Microbiology TODAY

41:4 November 2014

Water

Climate change and microbial life in the ocean
Viruses and algal blooms
The aquaculture industry
Microbiological treatment of used water
Legionnaires' disease

SOCIETY FOR GENERAL MICROBIOLOGY

CHLORAMPHENICOL

CAPSULES

Widely distributed throughout the body, including CSF[1]

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

Rarely implicated with *C.difficile*[3]

Effective against serious infections including:

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

Abbreviated Prescribing Information
Chloramphenicol Capsules BP 250mg

Presentation: Capsules containing 250mg chloramphenicol BP.
Indications: Typhoid fever and life-threatening infections, particularly those caused by *Haemophilus Influenzae*, where other antibiotics will not suffice.
Posology: For oral administration.
Adults and elderly: 50mg/kg body weight daily in 4 divided doses. For severe infections (meningitis, septicaemia), this dose may be doubled initially, but must be reduced as soon as clinically possible.
Children: Not recommended.
Contra-indications: Known hypersensitivity or toxic reaction to chloramphenicol or to any of the excipients. Should not be used for the prophylaxis or treatment of minor infections; during active immunisation; in porphyria patients; in patients taking drugs liable to depress bone marrow function; during pregnancy, labour or by breast-feeding mothers.
Special warnings and precautions for use: Use only if other treatments are ineffective. Use should be carefully monitored. Reduce dose and monitor plasma levels in hepatic or renal impairment in the elderly and in patients concurrently treated with interacting drugs.
Interactions: Chloramphenicol prolongs the elimination, increasing the blood levels of drugs including warfarin, phenytoin, sulphonylureas, tolbutamide. Doses of anticonvulsants and anticoagulants may need to be adjusted if given concurrently. Complex effects (increased/decreased plasma levels) requiring monitoring of chloramphenicol plasma levels have been reported with co-administration of penicillins and rifampicin. Paracetamol prolongs chloramphenicol half-life. Chloramphenicol may increase the plasma levels of calcineurin inhibitors e.g. ciclosporin and tacrolimus. Barbiturates such as phenobarbitone increase the metabolism of chloramphenicol, resulting in reduced plasma chloramphenicol concentrations. In addition, there may be a decrease in the metabolism of phenobarbitone with concomitant chloramphenicol use. There is a small risk that chloramphenicol may reduce the contraceptive effect of oestrogens. Chloramphenicol reduces the response to hydroxocobalamin. Chloramphenicol is contra-indicated in patients taking drugs liable to suppress bone marrow function e.g. carbamazepine, sulphonamides, phenylbutazone, penicillamine, cytotoxic agents, some antipsychotics including clozapine and particularly depot antipsychotics, procainamide, nucleoside reverse transcriptase inhibitors, propylthiouracil.
Pregnancy and Lactation: The use of chloramphenicol is contra-indicated as the drug crosses the placenta and is excreted in breast milk.
Effects on ability to drive and use machines: No significant effect on driving ability.
Undesirable Effects: Reversible dose related bone marrow depression, irreversible aplastic anaemia, increased bleeding time, hypersensitivity reactions including allergic skin reactions, optic neuritis leading to blindness, ototoxicity, acidotic cardiovascular collapse, nausea, vomiting, glossitis, stomatitis, diarrhoea, enterocolitis, Gray Baby Syndrome particularly in the newborn, which consists of abdominal distension, pallid cyanosis, vomiting, progressing to vasomotor collapse, irregular respiration and death within a few hours of the onset of symptoms.
Overdose: Stop chloramphenicol immediately if signs of adverse events develop. Treatment is mainly supportive. If an allergy develops, oral antihistamines may be used. In severe overdosage e.g. Gray Baby Syndrome, reduce plasma levels of chloramphenicol rapidly. Resin haemoperfusion (XAD-4) has been reported to substantially increase chloramphenicol clearance.
Pack size and Price: 60 capsules £377.00
Legal Category: POM.
Market Authorisation Number: PL17736/0075.
Market Authorisation Holder: Chemidex Pharma Limited, 7 Egham Business Village, Crabtree Road, Egham, Surrey TW20 8RB, UK.
Date of preparation: April 2012.
See Chloramphenicol Summary of Product Characteristics for full prescribing information.

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

References
1. Sweetman S.C. (ed), Martindale: The Complete Drug Reference. [online] London: Pharmaceutical Press <http://www.medicinescomplete.com/> (Accessed on 22 August 2011). **2.** Feder, H. Chloramphenicol: What we have learned in the last Decade. Southern Medical Journal. 1986; 79(9): 1129-34. **3.** Kelly, C., LaMont, T. Patient information: Antibiotic-associated diarrhea *(Clostridium difficile)*. www.uptodate.com. (Accessed on 11 August 2011). **4.** Fluit, A.C., Wielders, C.L.C., Verhoef, J., and Schmitz, F.J. Epidemiology and Susceptibility of 3,051 Staphylococcus aureus Isolates from 25 University Hospitals Participating in the European SENTRY Study. Journal of Clinical Microbiology. 2001; 39(10): 3727-3732. **5.** Weigel LM *et al.* High-Level Vancomycin-Resistant Staphylococcus aureus (VRSA) Associated with a Polymicrobial Biofilm. Antimicrobial Agents and Chemotherapy. Published online ahead of print on 30 October 2006. http://aac.asm.org/cgi/reprint/AAC.00576-06v1.pdf. (Accessed on 22 August 2011). **6.** Ensminger, P., Counter, F., Thomas, L., Lebbehuse, P. Susceptibility, Resistance Development, and Synergy of Antimicrobial Combinations Against *Clostridium difficile*. Current Microbiology. 1982; 7: 59-62. **7.** Poilane, I., Bert, F., Cruaud, P., Nicolas-Chanoine, MH., Collignon, A. Interest of the disk diffusion method for screening *Clostridium difficile* isolates with decreased susceptibility to antibiotics. PathologieBiologie (Paris). 2007; 55(8-9): 429-33. **8.** Cattoir, V., Ould-Hocine, ZF.,Legrand, P. Antimicrobial susceptibility of *Clostridium difficile* clinical isolates collected from 2001 to 2007 in a French university hospital. PathologieBiologie (Paris). 2008; 56(7-8): 407-11. **9.** Brazier, JS., Levett, PN., Stannard, AJ., Phillips, KD., Willis, AT. Antibiotic susceptibility of clinical isolates of clostridia. Journal of Antimicrobial Chemotherapy. 1985; 15(2): 181-5.

EG/CH/APR/2012/08

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ALLIANCE: 065995
MOVIANTO: CHL25060

ESSENTIAL GENERICS

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

Editorial

As I write this editorial the most recent Climate Summit is taking place in New York. It has been accompanied by more than 2,000 demonstrations staged in 150 countries, including marches in major cities such as Rio de Janeiro, Lagos and Bogotá. London saw more than 30,000 marchers backed by celebrities such as Emma Thompson, Vivienne Westwood and Peter Gabriel to raise awareness.

The Summit highlighted action and the need to build resilience in countries at '*greatest risk from rising sea levels, precipitation, droughts and extreme weather events that can destroy decades of development gains overnight*'.

The changes in movement and behaviour of both water systems and water cycles that accompany climate change include a re-sculpting of lands, a changing environmental biodiversity, and impacts on human wellbeing and health. The idea to devote this edition of *Microbiology Today* to water was conceived as Britain suffered some of the worst floods that it had seen for generations. Our relationship with water is changing and we were keen to explore how micro-organisms are also changing their interactions with this ubiquitous substance.

In this issue David Walsh's article explores this idea as he examines the consequences of climate change on microbial marine life, asking questions such as 'how many species are there in the ocean and what governs their distributions?' and 'what role do these highly diverse microbial communities play in the ocean food web and global biogeochemical cycles?' Mike Allen discusses the interaction between phytoplankton and the viruses that infect them. These infections cause the phytoplankton cells to lyse, releasing nutrients back into the seawater. This relentless lytic function is fundamentally important to global biogeochemical cycling and ecosystem function, which would collapse without the constant recycling of nutrients at the microbial level.

Brian Austin has written an article that examines the aquaculture industry. He outlines the benefit that this ancient industry has provided and continues to provide to world economies. However, there are also inherent risks of infection with the decision to farm large quantities of the same species in confined spaces.

Human health has been affected by contaminated water for millennia. Modern technology associated with our water use has had both a positive and a negative effect on human health. Mike Dempsey has written an article that describes how we use microbiological treatment of 'used' water to protect public health and the aquatic environment. On the other hand, I have written an article that describes how *Legionella*, a common microbe found in the environment, has become a health risk as we have created man-made water supplies. Other articles shine spotlights on the raft of imaginative, varied events that our Society and Society members have organised and undertaken to engage the public with the microbial world.

Finally the Comment piece, *Hydraulic fracturing: what do microbes have to do with it?* by Lee Stanish discusses the role that microbes play in groundwater quality and outlines our present understanding of how pollutants, (such as those caused by fracking) can alter the composition of groundwater microbial communities.

As this edition arrives though your letter boxes winter will be underway in the United Kingdom and the countries of the northern hemisphere. When it comes to storms, flooding and winter weather, I wish you all a kind one.

Laura Bowater
Editor
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TODAY

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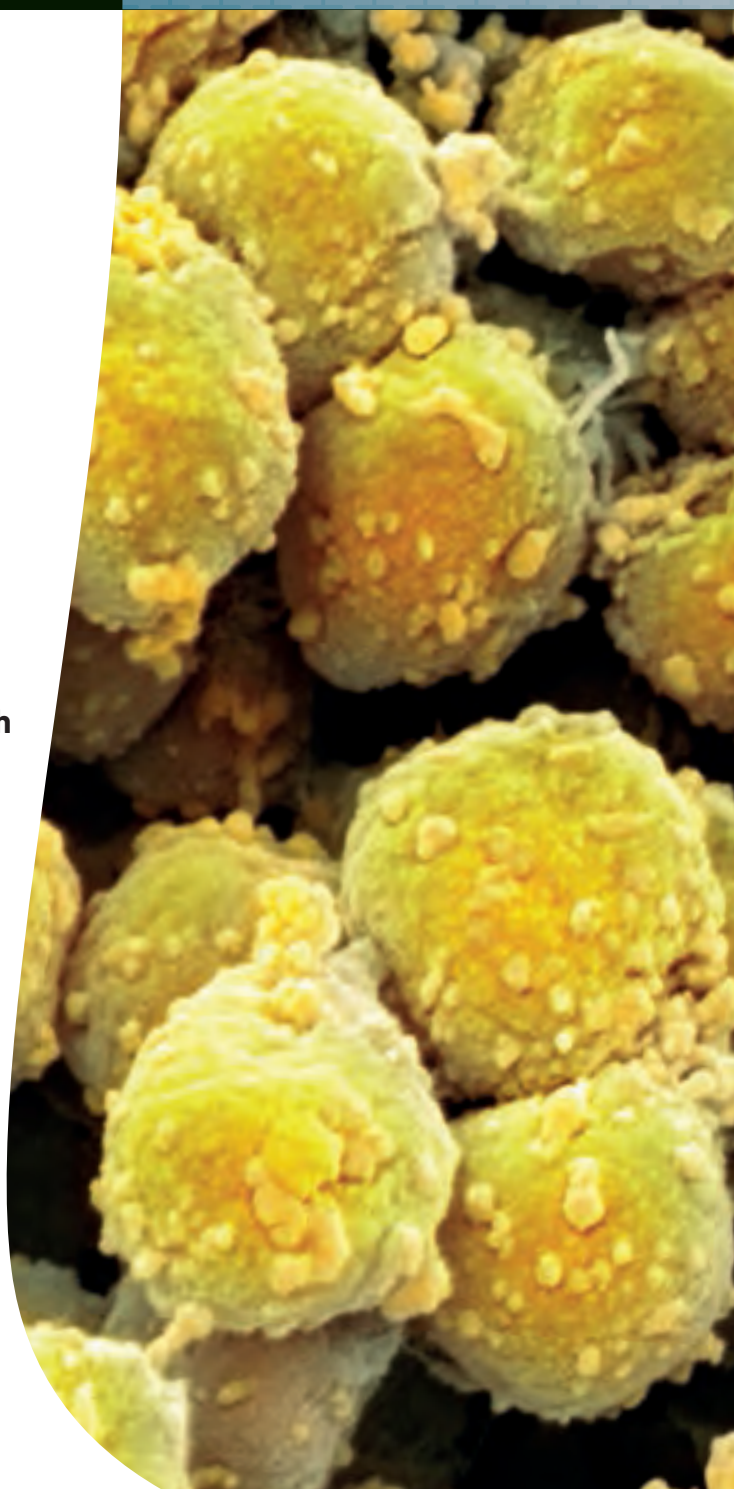

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Features

Regulars

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Design **Ian Atherton, Corbicula Design** (www.corbiculadesign.co.uk)

Printed by **Charlesworth Press, Wakefield**

ISSN 1464-0570

FSC Logo

Coloured scanning electron micrograph of fossilised diatoms. Steve Gschmeissner / Science Photo Library

SOCIETY FOR GENERAL MICROBIOLOGY

Council 2013–14

Executive Officers

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Scientific Conferences Committee – Professor Mark Harris

School of Molecular and Cellular Biology, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT; **m.harris@leeds.ac.uk**

From the President

As a Learned Society it is vital that we use our collective knowledge and understanding of our discipline to ensure that policy-makers are aware of global issues affecting and affected by our discipline. Members will be aware of my passion for the Society to engage in policy issues. We have already seen antibiotics voted as the topic of the Longitude Prize 2014 and there continues to be considerable public and press interest in antimicrobial resistance. However, this is not the only global issue of concern to microbiologists. Water, the theme of this edition of *Microbiology Today*, is another.

Photo Ian Atherton

I am writing this shortly after attending a meeting of the Society's Policy Committee, where we discussed, among other things, a Policy Roadmap for the Society. This is being actively developed with input from members and, if Council approves, will be rolled out in 2015. We hope that members will engage with microbiological issues in their locality, making the public and politicians aware of our interests and concerns. Several of the articles in this issue show what the Society and individual members are doing in outreach. Since our move to London, the Society is much more active in engaging with the national media. I am sure that more people have read a comment from me about *Legionella* and hot tubs in the *Daily Mail* than have read any of my scientific papers!

As we come towards the end of the calendar year, it is a good opportunity to mention membership subscriptions. Subscription rates are unchanged from last year and we have concessionary rates of membership with the same benefits as full members. If you know of someone who has allowed their membership to lapse for financial or other reasons, let them know about the membership categories on the website (**http://microb.io/1pTSeCk**) and that membership is for a full 12 months, irrespective of the date of joining. Under certain circumstances, such as childcare or carer responsibilities or disability, they may be eligible for an Inclusion Grant to attend meetings.

Although member subscriptions are an important source of income for the Society, the majority of our income comes through journal subscriptions and charges. Our journals have undergone many developments this year. A new manuscript submission system has been introduced and a range of policies have been developed to ensure compliance with funding body requirements. We also launched *JMM Case Reports*, the Society's first fully open access journal. The Publishing Committee and staff have been working hard to bring about these improvements and will continue to do so next year, with a new hosting platform for the journals due to launch in summer 2015. I encourage members to support the Society by submitting their next article to one of our journals. Standard publication is free, and discounts on open access fees are available for members. Information can be found at **www.sgmjournals.org**

I have now been President of the Society for just over two years. This has been a time of great change. In the November 2013 issue of *Microbiology Today* I flagged the changes that the Society had undergone during my first year, several instigated by our previous President, Hilary Lappin-Scott. The pace of change has, if anything, increased! In 2014, inter alia, we moved to London, we changed our branding, we published our Equality and Diversity policy and introduced new categories of membership, we introduced a new journal and publishing procedures, we have a new Chief Executive, we run a single Annual Conference and Focused Meetings series, our AGM is separate from our Conference, and we have Society Champions working on our behalf in various localities. What changes does 2015 hold for the Society for General Microbiology? Some are in the pipeline and I am sure that there will be many others. It is a privilege to represent such a dynamic and forward-looking society.

Nigel Brown
President
president@sgm.ac.uk

From the Chief Executive

One of the best things about working at the Society for General Microbiology is the opportunity to meet and engage with the members – scientists whose work reveals the mesmerising array of patterns and processes at work in the microbial world and the practical power of this knowledge in everyday life. During my first few weeks as Chief Executive, it has been a great privilege to start meeting some of you and learn more about your science. I have been struck by the affection the members have for the Society and by the many ways in which you help make the Society such a vibrant place to work.

The first Focused Meeting, on the subject of soil microbiology, was fascinating. The sheer range of science made the event a stimulating experience – from genetic comparisons of fungi, through field-scale studies of soil compaction, to global estimates of the amount of carbon locked up in soils; and of course this diversity mapped on to the huge variety of uses to which the science can be put. We heard about modelling to inform policies on climate change, the bioremediation of former industrial sites and a host of agricultural applications of microbiology. My favourite part was meeting Shorok Mombrikotb, a graduate student who had chosen not to attend a more glamorous international conference because she really wanted to take part in the Society's Focused Meeting. By lunchtime on the first day, she had met experts who could help advance her project with new samples and fresh insights.

Another of the events where I was able to meet members and find out about your work was the Annual General Meeting, which was coupled with the finals of the *Sir Howard Dalton Young Microbiologist of the Year* Competition. Not only did eight outstanding young researchers present on a wide variety of subjects, including HIV, food poisoning, herpesvirus, fungal infections and biofuels, we also saw senior scientists asking questions and continuing to learn from the young. At the President's Dinner afterwards, the young microbiologists sat with Council members, Honorary Members and representatives from the wider scientific community, with everyone learning something new and developing their professional networks. Well done not just to the winners but to everyone who took part in the competition; it showed just how much potential there is among the early-career members of the Society.

The third big event at which I engaged with Society members was Champions' Day. Eight of the Society's new Champions came together to develop their plans for ensuring that microbiologists across the UK and beyond can benefit from the Society's activities. The Champions will be arranging everything from a microbiology-themed pub quiz, organised by Marilia De Assis Alcoforado Costa in Dundee, to a symposium for early-career researchers from Alistair Walsham in Norwich. We could have called these energetic and resourceful people Ambassadors – but an ambassador is someone who takes instructions from headquarters and sticks to the official line. Champions are important individuals in their own right with their own ideas, and the Society sees its new Champions as a hugely important part of our efforts to enable you, the members, to get the maximum possible benefit from joining the Society.

The members' survey that we undertook earlier in the year demonstrated a big appetite among microbiologists to get more involved with Society activities, and to work with the staff to build programmes that help you advance your science and develop your careers. I hope to meet many more of you in the coming months and learn about your research and your aspirations for your own careers and for the Society. Please feel free to contact me, tell me what we do well and where you want to see more, invite me to come and see your lab, and let me have your ideas on how the Society can focus on what you need to continue delivering the fascinating range of microbiology that I have been learning about in my early weeks at the Society.

Peter Cotgreave
Chief Executive
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News

New article submission systems launched for all Society journals

The Society for General Microbiology's Publishing team has now begun using a new journal manuscript submission and tracking system, Editorial Manager. They have also launched ProduXion Manager, a new production tracking system. Both are provided by Aries Systems. Benefits include clear user interfaces, improved review processes and a transparent manuscript tracking system, which allows authors to monitor their article from submission through to publication. Please direct any queries about the move to Editorial Manager to **journals@sgm.ac.uk**

Membership rates 2015

The Society would like to thank all its members for their support over the past 12 months. The membership rates were agreed at the Annual General Meeting (AGM) of the Society on 11 September 2014. We are pleased to inform members that the membership rates for 2015 will be held at their current level. If you pay by credit card, you can renew your membership online at **www.sgm.ac.uk**. If you pay by direct debit you do not need to do anything further – your membership will be renewed automatically unless you have any changes to make.

Membership will now run for a full 12 months from the date you join, irrespective of when that is.

Members are reminded that their subscriptions for next year will be due soon. As in previous years, no journal or conference information will be dispatched to members who are in arrears.

Please contact the Membership Office on **+44 (0)20 7685 2691** or by email to **members@sgm.ac.uk** if you have any questions regarding your membership.

Membership subscription rates

Full Member	£65*/£75	US$145	€95
Full Concessionary Member	£28*/£33		€40
Postgraduate Student Member	£28*/£33	US$68	€40
Undergraduate Student Member	£10*/£15		€18
International Associate Member	£20	US$42	€24
School Member	£15		€18
Affiliate Member	£10*/£15	US$31	€18

*Direct Debit payment rates

JMM Case Reports

Article processing charges to be introduced for *JMM Case Reports* in 2015

From 1 January 2015, article processing charges (APCs) will be introduced for all accepted submissions to *JMM Case Reports*. These charges cover the cost of the editorial and production process. Our APCs will remain highly competitive, with discounts available for Society members, students, and authors from institutions who subscribe to its sister journal, *Journal of Medical Microbiology*.

Details of the new charges and how they will be applied can be found online at **http://microb.io/1ux6W7N**

Association for Science Education 2015

The Society will be returning to the Association for Science Education (ASE) annual conference from 7 to 10 January (**www.ase.org.uk**). The 2015 conference will be at the University of Reading and you'll find us in the Exhibition hall. If you are a teacher, PGCE student, technician or involved in science education, please come by for free resources (Key Stages 2, 3, 4 and 5) and chat about how the Society can help you with practical microbiology teaching. We look forward to seeing you!

Sir Howard Dalton Young Microbiologist of the Year

Ali Hussein receives his prize from President Nigel Brown.

At the President's Dinner, **Ali Hussein**, a PhD student from the University of Bath, was awarded first prize in the Sir Howard Dalton Young Microbiologist of the Year Competition.

Ali's talk, which he presented at the Society's AGM, covered his work on the thermophilic bacterium *Geobacillus thermoglucosidasius*, and his attempts to make it more efficient at digesting cellulose and hemicellulose. Professor Nigel Brown, the Society's President, presented Ali his prize. The first runner-up was **Maitreyi Shivkumar** (University of Cambridge), with **Lauren Ames** (University of Exeter) the second runner-up.

The Sir Howard Dalton Young Microbiologist of the Year Competition recognises excellence in science communication from a postgraduate or early postdoctoral Society Member who has presented a poster or an offered paper at the Society's Annual Conference or Irish Division Meeting. The presentations from the shortlisted finalists are judged by a panel comprised of members from the Society's four Divisions and Professional Development Committee. Full details on the prize can be found on the Grants & Prizes section on the website: **www.sgm.ac.uk/grants-prizes**

New members of Council, Committees and Divisions

Council are pleased to announce that the following members have been appointed to the Council, Committees and Divisions.

Council

The following members of Council will take up office from January 2015:

Mike Skinner (Elected Member)
David Whitworth (Chair of Professional Development Committee)
Charles Dorman (Chair of Publishing Committee)

Committees

The following members of Committees and Divisions will take office subsequent to the AGM 11 September 2014.

Professional Development Committee

Douglas Browning
Katherine Hargreaves

Virology Division

Erica Bickerton
Andrew Macdonald
Stephen Griffin
Jo Parish

Prokaryotic Division

Stephen Michell
Sheila Patrick
Lori Snyder
Martin Welch
Jennifer Mitchell
Ryan Seipke
Sabine Totemeyer

Eukaryotic Division

James Ajioka
Kevin Kavanagh
Edward Louis
Colin Robinson
Gareth Bloomfield
Jason King
Ian Roberts

Irish Division

David Clarke
Marguerite Clyne

Chair-elects of Committees

The following candidate has been recommended by their current committee to become Chair-elect:

Communications Committee

David Bhella

For more information about the Council, Committees and Divisions please visit **www.sgm.ac.uk/aboutus**

Deaths

The Society notes with regret the passing of three long-standing members of the Society, **Professor Alan Glyn** (member since 1967), **Dr Royall Moore** (member since 1973) and **Professor Axel Rethwilm** (member since 1994).

ICC, Birmingham, UK. Bob Hall

Annual Conference 2015

The Society is looking forward to welcoming members and non-members alike to the 2015 Annual Conference, which will take place from 30 March to 2 April at the International Convention Centre in Birmingham, UK. Whether you are a veteran microbiologist or just starting out in your career, the Conference is a must for everyone with an interest in microbiology providing world class science and excellent networking opprotunities. For further information go to page 178 or visit the Society's website (**http://microb.io/1vNRamX**).

Stand-alone Society Annual General Meeting and Celebration of the Society's Work

For the first time, the Society's Annual General Meeting (AGM) was held independently of a Society conference. **Professor Melanie Welham**, Executive Director of Science at the Biotechnology and Biological Sciences Research Council (BBSRC), delivered an inspiring keynote address, entitled *BBSRC strategy: a reflection on past and future opportunities for microbiology*.

Professor Welham praised the world-leading status of UK bioscience and noted the importance of microbiology throughout the range of BBSRC-funded science. Prior to the AGM, Public Relations Manager Dr Benjamin Thompson spoke with her about her research and her work at the BBSRC. The interview can be found on our website: **http://microb.io/1tN68fS**

Photographs showing the highlights from the AGM and President's Dinner can be found on pages 156–157.

Professor Melanie Welham

2014 Society Outreach Prize

Dr Joana Alves Moscoso

Dr Joana Alves Moscoso of Imperial College has been awarded the 2014 Outreach Prize. Joana is a co-founder of Native Scientist (**http://nativescientist.com**), an organisation that engages bilingual pupils in the UK about science in their native language.

We spoke to Joana in advance of our Annual General Meeting – read our Q&A with her on our website (**http://microb.io/1qN8hV4**).

Contributions and feedback

The Society welcomes contributions and feedback from members, particularly news items that appear in this section, future magazine theme suggestions and ideas for the Comment article. Please contact **mtoday@sgm.ac.uk** with ideas.

Dariel Burdass
Director of Strategy and Communications
d.burdass@sgm.ac.uk

Target gram-negative infections

Selexid® hits gram-negative bacteria hard. Its specific and high activity against most enterobacteriaceae, including *E. coli*, delivers proven efficacy in the treatment of UTIs.[1,2] In lower UTIs caused by ESBL-producing bacteria, Selexid® has demonstrated good clinical activity.[3-6]

Pivmecillinam is a pro-drug that is hydrolysed in the body to mecillinam and has a low impact on normal intestinal and vaginal microflora.[7-9] Equally important, Selexid® has a resistance rate of 1% in the UK and resistance levels are low (0.5%)* even in countries where Selexid® has been used for over 30 years.[10]

For targeted activity against gram-negative infections, select Selexid.®

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pivmecillinam hydrochloride

* ECO-SENS II study (2007-2008). Resistance rates are amongst *E. coli* from urinary tract infections in an adult female population. A resistance rate of 0.5% (n=203) was observed in Sweden and a rate of 1% (n=201) for mecillinam in UK.

Prescribing Information for Selexid® tablets
Please refer to full Summary of Product Characteristics (SmPC) (www.medicines.org.uk/emc) before prescribing.
Presentation: Selexid® tablets: each tablet contains pivmecillinam hydrochloride 200 mg.
Indications: Treatment of infections due to mecillinam sensitive organisms, including urinary tract infections (UTI) and salmonellosis. Preliminary experience in a small number of patients suggests that Selexid® Tablets may be a useful alternative antibiotic in the treatment of acute typhoid fever and in some carriers of salmonellae when antibiotic treatment is considered essential.
Dosage and administration: Oral administration. Tablets must be taken with at least half a glass of water; preferably taken with or immediately after a meal. Adults and children weighing more than 40 kg: UTI: acute uncomplicated cystitis: 72 hour course of 2 tablets immediately, followed by 1 tablet 3 times daily to a total of 10 tablets; chronic or recurrent bacteriuria: 2 tablets, 3 to 4 times daily. Salmonellosis: enteric fever: 1.2-2.4 g daily for 14 days; salmonella carriers: 1.2-2.4 g daily for 2-4 weeks. Children weighing less than 40 kg: UTI: 20-40 mg/kg bodyweight daily, in 3 to 4 divided doses. Salmonellosis: 30-60 mg/kg body weight in 3 to 4 divided doses. Elderly: Renal excretion of mecillinam is delayed; significant accumulation is not likely at the recommended adult dosage.
Contraindications: Hypersensitivity to constituents, penicillin or cephalosporin. Patients with known carnitine deficiency and infants under 3 months. Oesophageal strictures and/or obstructive changes in the gastrointestinal (GI) tract.
Precautions and warnings: During long term use, advisable to carry out routine liver and kidney function tests. Caution advised in patients with porphyria. As with other antibiotics excreted mainly by the kidneys, raised blood levels of mecillinam may occur if repeated doses are given to patients with impaired renal function. Use with caution for long-term or frequently-repeated treatment, due to possibility of carnitine depletion. Concurrent treatment with valproic acid, valproate or other medication liberating pivalic acid should be avoided. Tablets must be taken with at least half a glass of water due to risk of oesophageal ulceration.
Drug interactions: Clearance of methotrexate from the body can be reduced by concurrent use of penicillins. The methotrexate dose may need to be adjusted. Simultaneous administration of probenecid reduces the excretion of penicillins; hence increases blood levels of the antibiotic. Simultaneous administration of other beta-lactam antibiotics with Selexid® may produce a synergistic effect. Avoid concurrent treatment with valproic acid, valproate or other medication liberating pivalic acid.
Pregnancy and lactation: The drug, as mecillinam, crosses the placenta. Although tests in 2 animal species have shown no teratogenic effects, in keeping with current practice, use during pregnancy should be avoided. Selexid® can be used during breast-feeding and no effects on the infant are anticipated. However, as for other penicillins, trace quantities of mecillinam are excreted into breast milk with a possible risk of sensitisation and subsequent allergic reactions in a sensitised infant.
Side effects: The most frequently reported undesirable effects are GI disorders and various skin reactions. Common: Diarrhoea, vomiting, abdominal discomfort, nausea, abdominal pain. Uncommon: Headache, dizziness, vertigo, rash, fatigue. Not known: Thrombocytopenia, granulocytopenia, leucopenia, eosinophilia, anaphylactic reaction, antibiotic associated colitis, mouth ulceration, oesophageal ulcer, oesophagitis, hepatic function abnormal, slight reversible increase in some liver enzymes, urticaria, pruritus, angioneurotic oedema, carnitine decreased.
See SmPC for a full list of side effects. Legal Category: POM.
Product Licence Number and Holder: PL 00043/0048. LEO Laboratories Limited, Horizon, Honey Lane, Hurley, Maidenhead, Berkshire SL6 6RJ, UK.
Basic NHS Price: £4.50/10 tablets.
Last revised: February 2014.

Adverse events should be reported. Reporting forms and information can be found at: www.mhra.gov.uk/yellowcard. Adverse events should also be reported to Drug Safety at LEO Pharma by calling 01844 347333 or by email: medical-info.uk@leo-pharma.com.

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Further information can be found in the Summary of Product Characteristics or from: LEO Pharma, Horizon, Honey Lane, Hurley, Maidenhead, Berkshire SL6 6RJ, UK.

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Code: 1045/10031a. Date of preparation: March 2014.

If It's Not On, It's Not On

Sexually transmitted infections (STIs) have been on the rise in the UK over the last decade. Human immunodeficiency virus (HIV) and human papilloma virus (HPV) can cause death, untreated gonorrhoea and chlamydia may lead to pelvic inflammatory disease and reproductive complications, and syphilis and herpes can be passed to an unborn foetus if infected while pregnant. There is now an increase in strains of STIs which are resistant to antibiotics, particularly gonorrhoea. One of the ways to combat this rise in STIs is better sex education for young people within schools to understand safe sexual health practices and how STIs are treated. Current Personal Social and Health Education (PSHE) guidelines include statements on safer sex and HIV/AIDS and STIs, but teaching these sensitive subjects can be tricky.

To support the work of sexual health education in schools, the Society developed a play with Northumberland-based theatre company Théâtre Sans Frontières. The play, *If It's Not On, It's Not On*, follows the story of 17-year-old Luke, from his first awkward sexual experience through to frank discussions with his friends and his Dad, in a humorous adventure through the history of sexually transmitted infections. Both Luke and the audience discover the facts behind STIs, who is at risk, where to get help and advice, and much more.

Scenes from *If It's Not On, It's Not On*. Henry Williams

The play was very well received by both students and teachers, who enjoyed the mix of humour, drama and facts to discuss potentially embarrassing topics.

This play is suitable for anyone over the age of 14, young and old alike. In 2015 we will be taking the play on tour around the UK. If you would like the play to be performed at your event or school, please get in touch.

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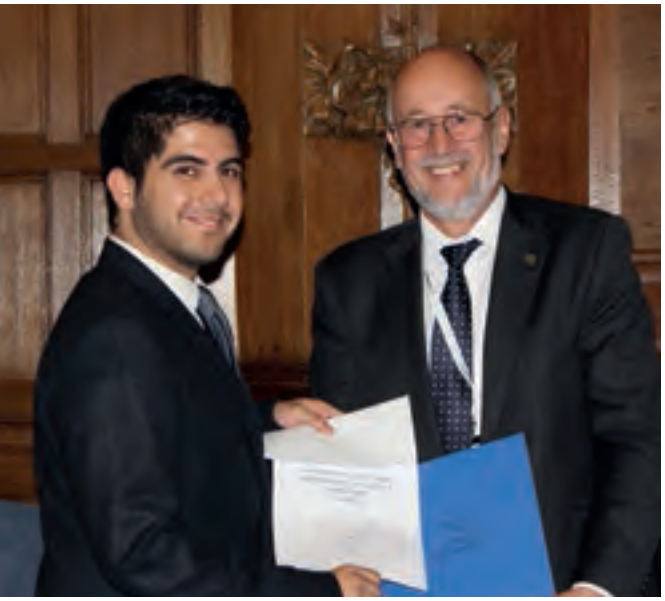
Annual General Meeting and Celebration of the Society's Work

The Annual General Meeting and Celebration of the Society's Work was held on Thursday 11 September in Charles Darwin House, Roger Street, London.

This was the first time that the Annual General Meeting had been organised as a stand-alone event and it provided an excellent opportunity to inform, reflect on, and celebrate the work of the Society over the past 12 months. Following the President's welcome the audience was treated to eight first-class scientific presentations from the finalists of the Sir Howard Dalton Young Microbiologist of the Year Competition and an inspiring talk from the Outreach Prize Winner on both the importance of outreach and the project she had set up to engage bilingual school students about science in their native language.



The Society was delighted to have such a prominent speaker as **Professor Melanie Welham**, Executive Director of Science at the Biotechnology and Biological Sciences Research Council (BBSRC) to present the special lecture, entitled *BBSRC strategy: a reflection on past and future opportunities for microbiology*. The afternoon concluded with a drinks reception where members were able to chat informally with the Society's Council and committee members. Staff were also on hand to explain more about the activities the Society is delivering to promote the 'art and science' of microbiology. This new format was a great success with over 50 people attending.

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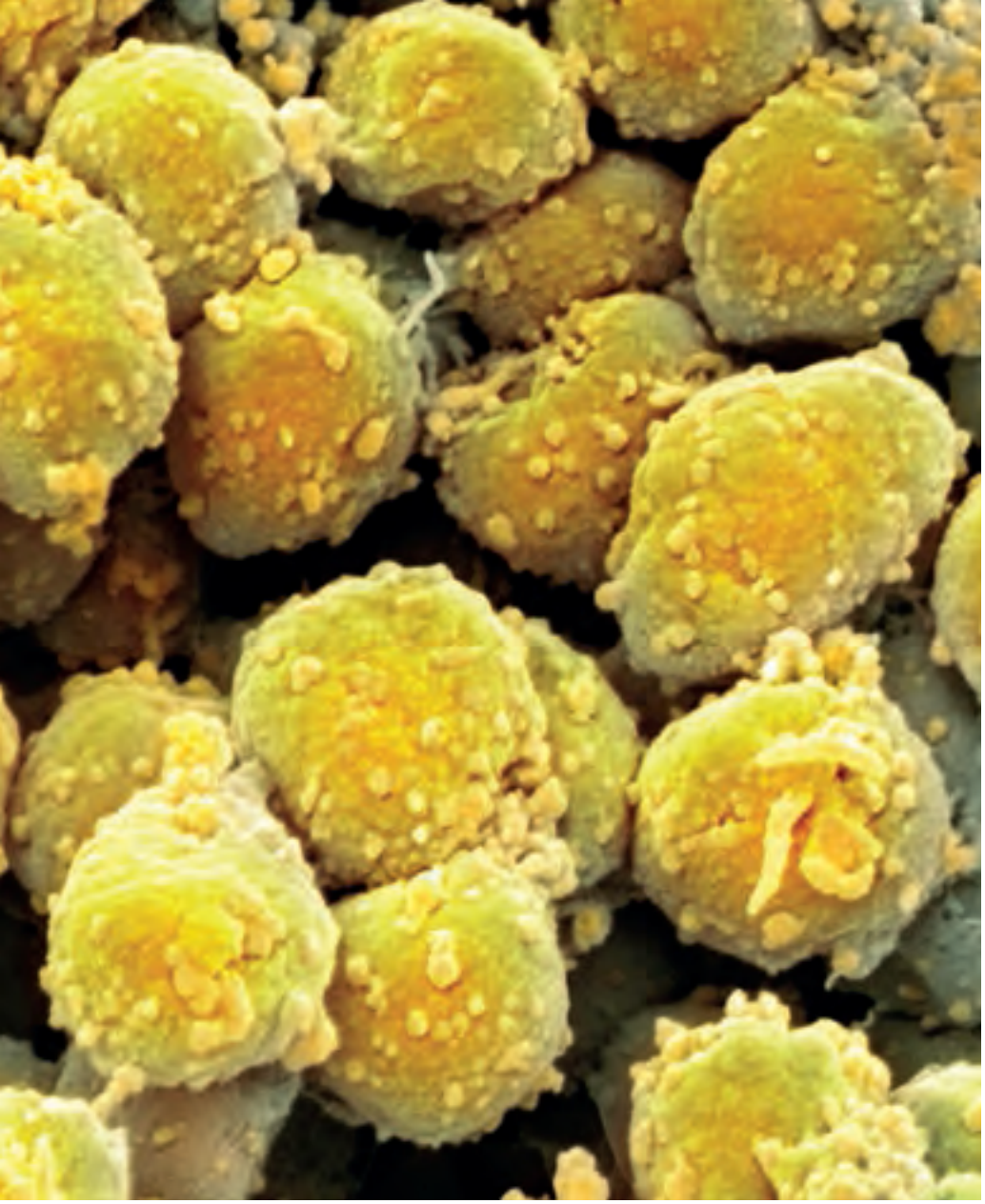
Consequences of climate change on microbial life in the ocean

David A. Walsh

Almost 2,400 years ago the Greek philosopher Aristotle would visit fishermen early in the morning to observe and systematically classify marine life with his naked eye. Unfortunately for Aristotle and the centuries of scientific inquiry that followed him, the naked eye is a woefully inadequate instrument for observing the vast majority of life in the sea. Covering over two-thirds of the Earth's surface and having an average depth of nearly four kilometres, the ocean represents 97% of the planet's biosphere. Examined under the microscope, every drop of seawater is the habitat of thousands upon thousands of tiny single-celled micro-organisms. Multiplied by the volume of the ocean, there are an unimaginable 10^{29} of these microbial cells. The vast majority of the ocean's biodiversity is comprised of microbial species.

Microbes and the marine food web

In the sunlit top layer of the ocean, plant-like micro-organisms called phytoplankton use the energy of the sun to combine carbon dioxide with water, making organic matter and – as a lucky metabolic byproduct – oxygen. Given the size of the ocean, it is not surprising that we can thank these phytoplankton for supplying half the oxygen we breathe. This primary production is also a cornerstone of the ocean food web analogous to plant production on land. The phytoplankton are consumed by small grazers, who in turn are eaten by others, including crustaceans, fish, and ultimately



False-coloured scanning electron micrograph (SEM) of archaea, a group of single-celled micro-organisms that are similar to, but evolutionarily distinct from bacteria. Steve Gschmeissner/Science Photo Library

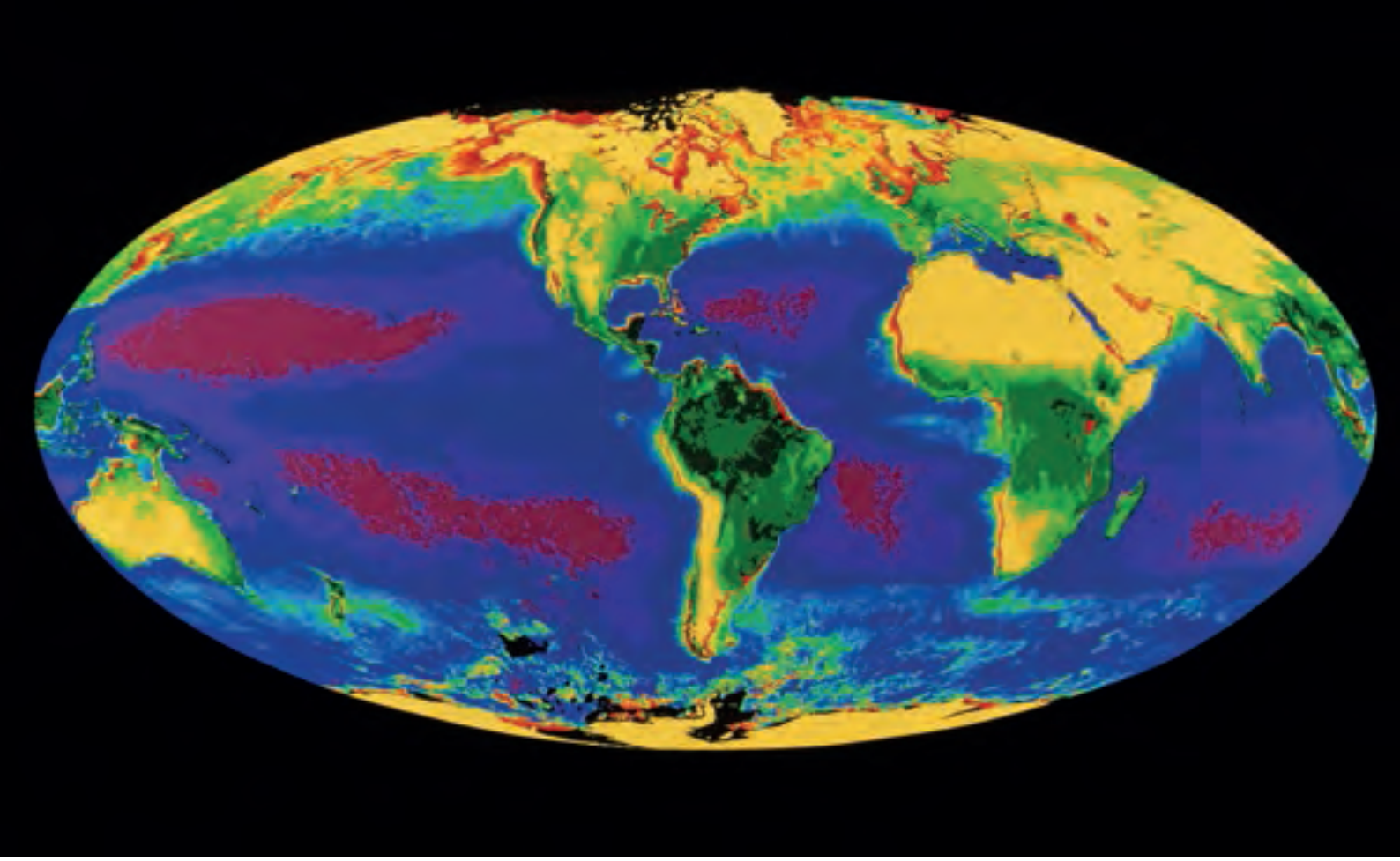
mammals such as whales and the polar bear.

What happens to the carbon fixed by phytoplankton and consumed by higher trophic levels? One possibility is that it simply sinks to the seafloor in its various forms, ranging from dead phytoplankton to blue whales. Most of it won't reach the bottom. Why? Because phytoplankton are not the only micro-organisms in the ocean. There is a second microbial cornerstone of the ocean food web known as the heterotrophic bacteria and archaea, tiny and diverse cells simply referred to as bacterioplankton. If you have ever left a head of lettuce or a leg of chicken in your refrigerator, only to return and find a pool of brown ooze and a rotten stench, then you are already familiar with the role bacterioplankton play in the marine food web. They are responsible for a process known as remineralisation, the breakdown of complex organic matter to carbon dioxide and essential inorganic nutrients (ocean fertilisers, if you will).

So, why doesn't the ocean stink? Well, in some places it does. At highly productive coastal locales where plenty of nutrients are welled up from the deep water by the winds, the slow remineralisation of macroscopic organisms produces those stinky byproducts of organic matter decay. But, in the massive clear surface waters of the open ocean, primary production is tightly coupled to remineralisation; organic matter directly released from phytoplankton is rapidly consumed by bacterioplankton, complicating and limiting carbon and energy transfer up the food chain. Some of the carbon goes into building new bacterioplankton cells, but a great deal is returned to the water and atmosphere as carbon dioxide. In effect, the cells 'burn' the carbon to produce the energy required for survival and reproduction. At the same time, bacterioplankton play a critical role by regenerating the nutrients required to sustain primary production.

The organic matter that escapes recycling at the surface is still transformed by bacterioplankton on its long journey to the deep ocean. Some is remineralised to carbon dioxide, releasing nutrients in the deep ocean. The deep ocean is effectively a rich fertiliser that, when mixed back up into the sunlit surface waters, stimulates phytoplankton growth. Some carbon is transformed into complex organic compounds that are not accessible to further degradation by bacteria or any living organisms. This recalcitrant organic matter drifting around in the deep ocean is the largest carbon reservoir on Earth. In fact, about 15% of the organic matter produced in the surface ocean is pumped by marine organisms into the deep, where it is 'stored' for thousands of years. This biological pump, mediated by micro-organisms, can be thought of as a massive carbon processing system that effectively scrubs carbon dioxide from the atmosphere.

Under the right conditions some of the organic matter reaches the seafloor



False-colour satellite image of Earth's biosphere, showing the distribution of vegetation on land and phytoplankton in the oceans. The colours represent chlorophyll densities: from red (most dense) through yellow and blue to pink (least dense) in the oceans; and from dark green to pale yellow on land. Dr Gene Feldman, NASA GSFC/ Science Photo Library

and becomes buried. Millions of years later it is transformed into the oil that we use to fuel vehicles and make plastics. Over geological time scales primary production at the ocean surface has the additional effect of storing carbon deep in the Earth, only to be released en masse by humans later in time.

In this way, phytoplankton and bacterioplankton play a crucial role in the global carbon cycle, the circular path by which carbon flows from the atmosphere into the biosphere, land, ocean and back again. In fact, since the beginning of the 19th century, the ocean has devoured about half of the carbon dioxide emitted from burning fossil fuels, offsetting accumulation of this greenhouse gas in the atmosphere. Some oceanographers have estimated that if the microbes in the upper ocean stopped pumping carbon down to the deep sea today, atmospheric carbon dioxide levels would eventually climb another 50% from their present state, accelerating global warming further. One is then left to wonder: will global warming influence these critical microbes? And if so, will microbial activities accelerate or reduce the impact of global warming?

Global warming and phytoplankton

The ocean regulates Earth's climate. Among other ways, it does so by exchanging heat with the atmosphere, storing it and distributing it around the globe. As the atmosphere warms so does the ocean – the surface layer most rapidly. Although far from certain, several studies have predicted the consequences of global warming on marine microbial communities. One line of reasoning goes like this: as the ocean surface warms it becomes less dense and tends to float on top of the cold nutrient-rich deeper water. Without replenishment of the nutrient fertiliser from below, phytoplankton in the warm

Since the beginning of the 19th century, the ocean has devoured about half of the carbon dioxide emitted from burning fossil fuels, offsetting accumulation of this greenhouse gas in the atmosphere.

top layer will starve, leading to reduced primary production and a corresponding decrease in carbon pumping to the deep sea. Is there evidence for this? Yes, scientists can use satellites to measure changes in phytoplankton productivity at a global scale. Over several years, they have shown that sea surface warming in stratified regions of the ocean is accompanied by reductions in productivity. This is not good news. However, the story is far from that simple. On a perhaps more positive note, primary production may in fact increase at high latitudes as chilly waters warm.

Size matters too. Research shows a significant negative relationship between temperature and phytoplankton cell size. In the Arctic, an ocean facing a particularly large and rapid period of change, the smallest species of phytoplankton are blooming while larger species are wilting away. Smaller cells have a higher surface-to-area ratio, providing more effective acquisition of nutrients. The problem is that large cells sink more quickly than smaller ones. So if projections are true and phytoplankton cell size will decrease with global warming, then we may see a further decrease in carbon pumped into the ocean interior due to a shift to smaller, more buoyant cells.

What about bacterioplankton?

Of all the microbes in the sea, phytoplankton have received the most attention. What about those heterotrophic bacterioplankton? Can we predict their response to a warmer ocean? Maybe, but the critical data on their distributions and activities in the ocean and through time is much more sparse than for phytoplankton. One way of looking at it is to treat bacterioplankton as a black box: organic matter enters the box, carbon dioxide and nutrients exit the box. This bulk process has been measured for many years in many places. From this data, the general prediction is that as temperatures rise in the open ocean, this process will tend to increase. Of course it is much more complicated than that, but if true, it seems that in a warmer ocean microbial processes will play an even more important role in the carbon cycle.

Peering into the microbial black box with genomics

What happens if you open that microbial black box and peer inside? In the early 2000s, marine microbiologists began applying genomics to studying the biodiversity in the sea. By sequencing DNA extracted directly from the microbes in seawater and analysing the genes, new forms of metabolism were discovered. In a classic study, scientists discovered genes for phototrophy – the process of harvesting energy from light – in bacteria previously assumed to rely exclusively on organic matter for energy. Even more exotic metabolisms have since been discovered in the sea. There are bacteria that use noxious hydrogen sulfide as an energy source, and archaea that use ammonia in the same manner. Both use organic matter as a source of carbon, but also fix carbon dioxide in much the same way as phytoplankton. These studies and others have demonstrated bacterioplankton play a much greater and more complicated role in marine food webs than simply breaking down organic matter and recycling nutrients to phytoplankton. The challenge is to understand how such newly discovered microbial life forms fit into the marine food web and influence biogeochemical cycles. Until we know, we can only speculate on how they are influenced by climate change.

Microbes as sentinels of change

The microbial world is often left out of discussions of climate change but as critical players in the carbon and other biogeochemical cycles, their responses to global warming demand attention. More worrying, climate change is leading to a warmer ocean, but an ocean that is also changing in other profound ways. Carbon dioxide accumulation is leading to ocean acidification. Oceanic stratification is resulting in the expansion of oxygen-depleted dead zones. At present, the jury is out on how microbial food webs and biogeochemical cycles will be influenced by these fundamental changes to Earth's largest ecosystem.

As a final note, studies are beginning to show marine microbes could serve as sentinels to monitor climate change effects on marine ecosystems. If so, there is a critical need for long-term time-series biological measurements of marine environments if we are to accurately predict change. We may have come a long way since Aristotle, but much about the microbial ocean remains a mystery.

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Algal blooms and viruses

Michael J. Allen

Most marine scientists have a love–hate relationship with dolphins, sharks, whales and turtles. They tend to get all the public's attention. We have pictures of them on our walls, own cuddly toys in their likeness and amuse our children with animated tales about their fictional adventures. Unfortunately, they distract from the real beauty and interest in the marine environment: the microbes, and in particular, the viruses.

An example of a recent algal bloom in the Baltic.
NERC Satellite Receiving Station, Dundee University

Swimming with dolphins is a once in a lifetime opportunity for most people, yet whenever you take a dip in the sea you will immediately come into contact with billions of single-celled organisms and viruses. Since life evolved in the sea and crawled out onto land only a billion years ago, this microscopic community has an extra two billion years of evolution and genetic novelty over the metabolically dull dolphins and whales that crawled back in hardly any time ago.

The Earth is undoubtedly a blue planet, covered predominantly in water. We tend to think of the land plants as providing the oxygen we breathe, but in reality just as much oxygen comes from the single-celled, photosynthetic microalgae (known as phytoplankton) that float freely in our oceans. Yet most of the time our oceans don't look like pea soup, and that's because these algae get eaten by zooplankton, which then get eaten by fish, which then get eaten by bigger fish and so on.

However, the fate of phytoplankton is not limited to just being eaten: cellular destruction following viral infection also plays a major role.

Viruses are the most abundant biological entity on the planet, and can number in excess of 100 million in just one teaspoon of seawater. With an estimated 10^{31} viruses in the ocean responsible for 10^{21} infections every second, they are responsible for the destruction of up to half of the marine microbial community on a daily basis. This relentless lytic function is of fundamental importance to global biogeochemical cycling and ecosystem function, which would collapse without the constant recycling of nutrients at the microbial level.

Algae are highly opportunistic and, when conditions are right (for example, when a new source of nutrients becomes available, or when light and temperature become more favourable), phytoplankton species can swiftly come to dominate communities. These are known as algal blooms and are typified by single algal species reaching concentrations of over a billion cells per litre over large tracts of water bodies. Harmful red tides caused by toxic dinoflagellates such as *Karenia brevis* and *Alexandrium fundyense* are well-known examples of such community takeovers. In addition to causing water discoloration, they often produce toxins which can decimate fisheries and cause paralytic shellfish poisoning in humans. However, with all those viruses floating around and a relatively homogenous host population dominating in one region, viral infection becomes almost inevitable. Viruses have been found to be one of the major causes of bloom demise. Blooms offer a fantastic opportunity to isolate viruses. In July, a virus (AaV, 371 kbp, 377 genes) was described that infects the brown-tide-causing alga *Aureococcus anophagefferens*. AaV was estimated to be present at abundances as high as 10^{20} particles following a bloom.

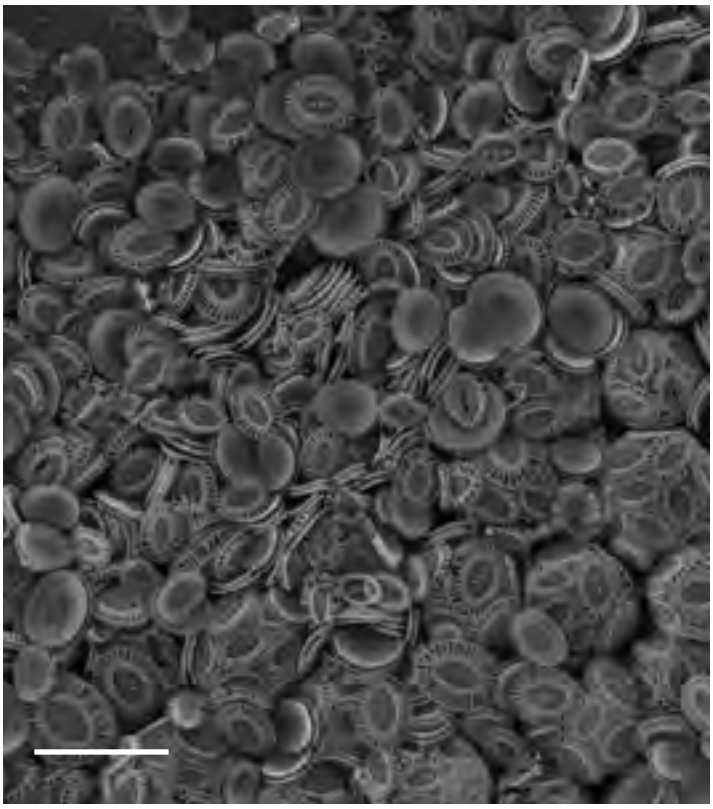
Emiliania huxleyi

Perhaps the most famous of all the phytoplankton, the coccolithophore *Emiliania huxleyi* has global distribution and is well known for forming both coastal and open ocean blooms in temperate latitudes than can cover up to 100,000 km^2. As the most abundant and ubiquitous coccolithophore in modern oceans, it has become a key species for studies on global biogeochemical cycles and climate modelling. In a world obsessed with carbon footprints and

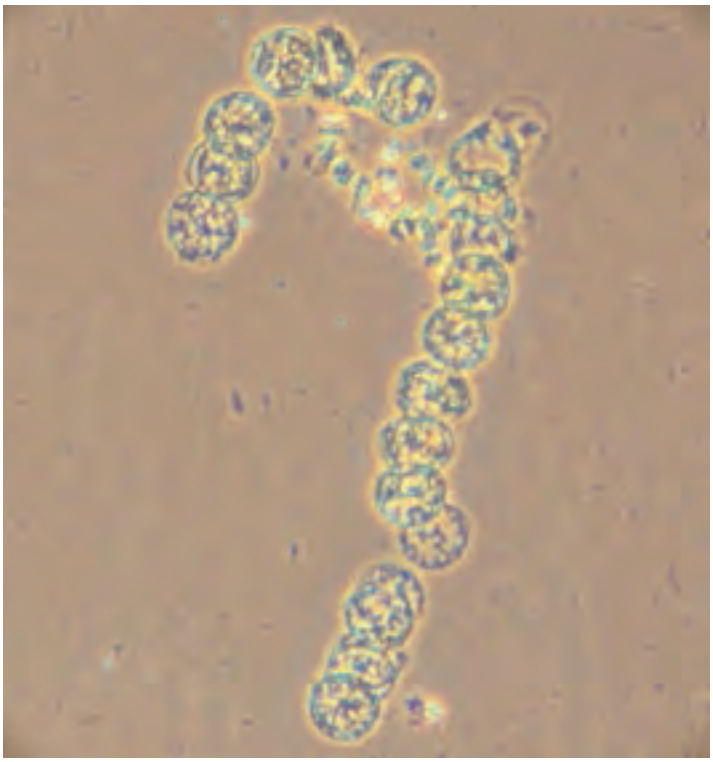
emissions, *E. huxleyi* stands out as an organism capable of both fixing carbon dioxide, and of sequestering carbon in an inorganic form during the construction of its elegant chalk outer scales, known as coccoliths. Measuring just a few micrometres in diameter, but growing to high concentrations during times of blooming, over geological time, the release of its coccoliths to the ocean floor is capable of forming structures such as the White Cliffs of Dover. Amazingly, the death of these algae is even thought to influence the weather. When dimethylsulfoniopropionate (DMSP), which is used as an intracellular osmolyte, is released following cellular disintegration, it is rapidly cleaved to produce dimethylsulfide which rises up to the atmosphere, becomes oxidised and forms cloud condensation nuclei. Viruses will also help to accelerate all of these processes. Given the attention lavished upon *E. huxleyi*, it is unsurprising that coccolithoviruses have been isolated during *E. huxleyi* blooms. Indeed, the classical milky waters produced towards the end of *E. huxleyi* blooms (which can even be seen from space) are not full of healthy *E. huxleyi* cells at all; they comprise mostly dead and infected dying cells that have released their liths into the surrounding waters. When sampled, these milky waters are usually full of coccolithoviruses (EhVs).

Giant viruses

Algal viruses have a profound impact on the global ecosystem. However, they have also gained attention for another reason: their size. The coccolithoviruses have been integral to changing the way we think of viruses. With gigantic genomes in excess of 407 kbp, these double-stranded DNA viruses contain



E. huxleyi **(intact cells to the right) viewed under an electron microscope. Over geological time the coccoliths (to the left) released fall to the seabed to form structures like the White Cliffs of Dover. Bar, 5 µm.** Mike Allen and Paul Rooks



An alga from a bloom at the Western Channel Observatory in April 2012 viewed under a phase contrast microscope. Mike Allen

HIV manages to decimate the multicellular human body and its complex defence system with a mere nine genes in its genomic armoury. With nearly 500 genes and a single-celled host approximately five microns in diameter, the coccolithoviruses have revealed a complexity to viral infection that we had never observed before.

The study of giant viruses often requires the use of giant bags (mesocosms), which can be filled with seawater and studied under natural conditions. Willie Wilson and Mike Allen

almost 500 genes. HIV manages to decimate the multicellular human body and its complex defence system with a mere nine genes in its genomic armoury. With nearly 500 genes and a single-celled host approximately five microns in diameter, the coccolithoviruses have revealed a complexity to viral infection that we had never observed before. Perhaps the most startling observation that can be made about EhV genomes is their genetic novelty: the vast majority of genes (>80%) are of unknown function and contain few database matches of note. The coccolithovirus genome, published shortly after its more famous cousin, the mimivirus (1,181 kbp, 911 genes), has opened our eyes to a new type of virus that seems to know no limits with regards to genomic size, content or complexity.

The term 'girus' (for giant-virus) was coined to refer to this new group of viruses, found within the nucleocytoplasmic large DNA virus family (NCLDV, a family which also includes the poxviruses). In the last decade, new viruses have been isolated including the Cafeteriavirus (730 kbp, 544 genes), Pithovirus (610 kbp, 467 genes), Sambavirus (1,213 kbp, 938 genes), Megavirus (1,259 kbp, 1,120 genes) and the recent Pandoravirus (~2,770 kbp, 2,556 genes). Each new giant virus has proven to be remarkably diverse; despite their shared evolutionary history, a mere dozen or so genes can be found in common between them. The Pandoravirus in particular is very interesting: despite its isolation in *Acanthamoeba polyphaga*, a host evolutionarily distant from the eukaryotic microalgae, its closest relative is the coccolithovirus.

There are certainly interesting times ahead in the study of algal viruses as their role in the decimation of algal blooms is understood with increasing clarity and the secrets of their genomes becomes unveiled. The major challenge marine virologists used to be concerned with was understanding and defining their impact in the global ecosystem; recent progress now suggests an understanding of their molecular modus operandi will prove a worthier challenge. Algal blooms are just the beginning of the story.

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Further reading

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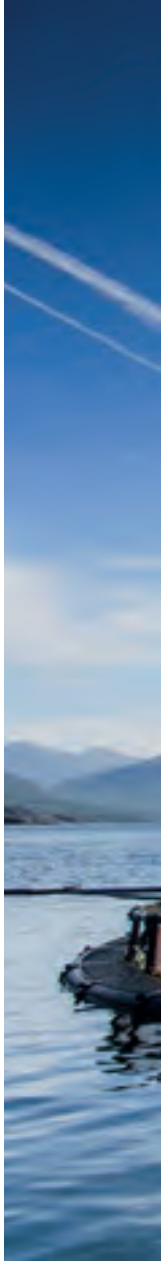

Aquaculture is the rearing of aquatic species under controlled conditions, and includes the production of fish (carp, salmon and trout, and tilapia predominate), shellfish (particularly penaeid shrimp, oysters and clams), plants (seaweeds), alligators, amphibians, crocodiles and turtles. The process includes self-contained processes starting with the acquisition of eggs and sperm (milt) from dedicated brood stock through to market-sized individuals, such as Atlantic salmon (*Salmo salar*). Aquaculture also involves the capture of juveniles from the wild with subsequent ongrowing to adult size in contained facilities. This is presumed to have been the original method that initiated aquaculture. Love it or hate it; aquaculture is an old, well-established industry, and it is here to stay.

The aquaculture industry

Brian Austin

The origin of aquaculture

Aquaculture may be traced back to common carp (*Cyprinus carpio*) culture in China, which is considered to have been developed during 2000–1000 BC. Fan Lai (a politician turned fish culturist, in ancient China during the 5th century BC) wrote a landmark publication on fish culture in ~500 BC; this was the earliest known monograph on carp culture. Since then, aquaculture has expanded to most countries, particularly in the years after the Second World War.

The reasons for aquaculture

The commonly held belief is that aquaculture provides food for the masses in developing countries, and high-value species, e.g. flounder and turbot, for the richer members of society. However, in addition, aquaculture is used to produce:

- animals for re-stocking waterways for subsequent capture by anglers
- ornamental fish, e.g. goldfish and Koi carp, for the pet industry
- specimens for biotechnology (to prevent the harvesting of possibly rare species from the wild)
- rare species for release into the aquatic environment, to protect biodiversity.

The size of the industry

Currently, more than 220 aquatic species are cultured, with the total worldwide production amounting to over 90 million tonnes in 2012 (Table 1). Ten of the top 14 aquaculture-producing countries are in Asia (Table 1); Norway having the highest production (of Atlantic salmon) in Europe. This global amount compares with just over 92 million tonnes of aquatic products obtained from harvesting wild species. The prediction is that aquaculture will continue to grow (the current annual growth rate is around 7% in all areas except sub-Saharan Africa, the Arctic and Antarctic), and quickly overtake the harvesting of wild species,

A collection of salmon pens in Scotland. Gustoimages / Science Photo Library

and become the dominant provider of aquatic plants and animals, worldwide.

Aquaculture in the UK

In England, the total aquaculture production is ~20,000 tonnes, with rainbow trout (*Oncorhynchus mykiss*) as the predominantly farmed species. In contrast, production of the dominant species, Atlantic salmon, has soared in Scotland to 164,000 tonnes with a value of £550 million in 2012. With the added value of smoked salmon, aquaculture has become the biggest agricultural export product in Scotland, and looks likely to grow even bigger. Indeed, the Scottish Government has set aquaculture ambitious targets for 2020, i.e. a 50% increase in Atlantic salmon production to 210,000 tonnes and a doubling of shellfish production to 13,000 tonnes.

Aquaculture sites

Aquaculture may occur in freshwater, estuarine or marine habitats, and involve pond (Fig. 1), tank (Fig. 2) and cage culture systems (Fig. 3) for fish, ponds and tanks for shrimp, and ropes suspended in the water column for bivalves. Ponds are essentially holes in the ground that may be lined with concrete or plastic; tanks may be on the surface or sited in the ground. There is

Table 1. The biggest producers in 2012

Data from FAO

Country	Production (million tonnes)	
	Animals	Plants
Bangladesh	1.7	–
Brazil	0.7	–
Chile	1.0	–
China	41.1	12.8
Egypt	1.0	–
India	4.2	–
Indonesia	3.0	6.5
Japan	0.6	0.4
Korea, South	0.4	1.0
Myanmar	0.8	–
Norway	1.3	–
Philippines	0.7	1.5
Thailand	1.2	–
Vietnam	3.0	0.2
Total	**66.6**	**23.7**

a long-term goal to move marine cage production well offshore into deep water, although there are engineering issues, such as resilience to storms, that need to be overcome. Sites range in size from those capable of producing a few tonnes up to those producing thousands of tonnes. The former may provide production locally for restaurants or village communities whereas the larger sites serve national and international markets. A topical example includes the catfish (*Pangasius*, also known as river cobbler), which is farmed extensively in the Mekong Delta of Vietnam, and sold widely in British supermarkets.

In many parts of the world, aquaculture sites are located so close to each other that effluent from one site is the inflow for another. This raises the problem about the spread of disease: these challenges include those of a microbiological nature.

Fig. 1. **Concrete-lined ponds used for the production of trout in Southern Bulgaria.** Brian Austin

Fig. 2. **Covered tanks used to grow juvenile Atlantic salmon in Scotland.** Brian Austin

Microbiological issues

Spoilage

It is speculative how much production may be lost to spoilage after harvesting, with culprits including *Shewanella putrefaciens*, which produces trimethylamine from trimethylamine oxide in fish tissues. Trimethylamine is odorous, and is a characteristic indicator of spoilage.

Disease

A wide range of organisms, including bacteria, viruses and eukaryotic parasites, are associated with disease, which may decimate production and render the survivors unsalable because of the presence of unsightly lesions. Epidemics do occur, and may have profound consequences for local economies. For example, infectious salmon anaemia, a Listed Disease by the World Organization for Animal Health, was the latest in a long line of diseases that devastated Chilean salmon production during 2007–2011 when production plummeted by several hundred thousand tonnes, leading to the loss of jobs and social unrest in the rural areas of the south.

First reported in 2009, early mortality syndrome (EMS) has spread across Asian shrimp production, notably white-leg and black tiger shrimp, causing heavy (up to 100% within 30 days) losses in China, Malaysia, Thailand and Vietnam. The condition is infectious, and has been linked with *Vibrio parahaemolyticus*. EMS has followed on from white spot syndrome (caused by Whitespot Syndrome Baculovirus complex), which led to the virtual collapse of the shrimp farming industry in China during 1993, spreading across southern and eastern Asia by 2011, and resulting in substantive losses.

Aeromonas salmonicida, which is the cause agent of a haemorrhagic septicaemia termed furunculosis, has been a major problem of salmon and trout culture in the UK, although currently it is less problematic. Instead, the organism may be found in carp culture, particularly in Eastern Europe where it causes unsightly ulcers, including a condition known as carp erythrodermatitis (Fig. 4).

The threat of disease has prompted detailed research into the development

It is predicted that aquaculture will become the dominant provider of aquatic species for consumption, re-stocking, visual display (pet fish) and biotechnology.

Fig. 3. **Cages used to farm Atlantic salmon in Scotland.** Brian Austin

Fig. 4. **Carp erythrodermatitis. This disease is attributed to an atypical form of *A. salmonicida*.** Pety Orozova

of suitable control measures. From the previous dominance of antibiotics and other antimicrobial compounds, attention has moved towards water treatments/disinfection, vaccines, immunostimulants and better management regimes. In Asia, much work has focused on the benefit of probiotics and plant products that confer health benefits, including protection against specific diseases.

Zoonoses

Fortunately, there is only limited evidence for the occurrence of human diseases resulting from exposure to aquaculture. There is some evidence for *Aeromonas*, *Edwardsiella*, *Erysipelothrix*, *Mycobacterium*, *Streptococcus* and *Vibrio* infections resulting from exposure to fish or shellfish. In 1996, the *Toronto Star* reported seven *Streptococcus iniae* infections in humans after buying and handling tilapia. The presumption was that the organism moved from the tilapia to the humans. A second example is *Vibrio vulnificus*, which may infect humans leading to fatalities through the consumption of contaminated molluscs. To re-iterate, the incidences of these infections is mercifully rare.

Conclusions

It is predicted that aquaculture will become the dominant provider of aquatic species for consumption, re-stocking, visual display (pet fish) and biotechnology. However, it is essential that we strive for a resilient and sustainable industry that has minimal impact on other users of the aquatic environment.

Brian Austin

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Processes for the treatment of used water involve fascinating microbiology, as they show how we control the impact of microbes on us and how we use them to control our impact on the environment. Examples include breaking the cycle of water-borne disease, such as protists that remove the causative agents of cholera and typhoid, as well as microbes involved in environmental protection where organic matter is mineralised and the mineralised nutrients are removed. In addition, a variety of processes harness the metabolic capabilities of bacteria involved in the phosphorous and nitrogen cycles. Furthermore, methane synthesis is used to destroy waste organic matter, using a complex community of bacteria and archaea, and thus capture this powerful greenhouse gas for use as fuel.

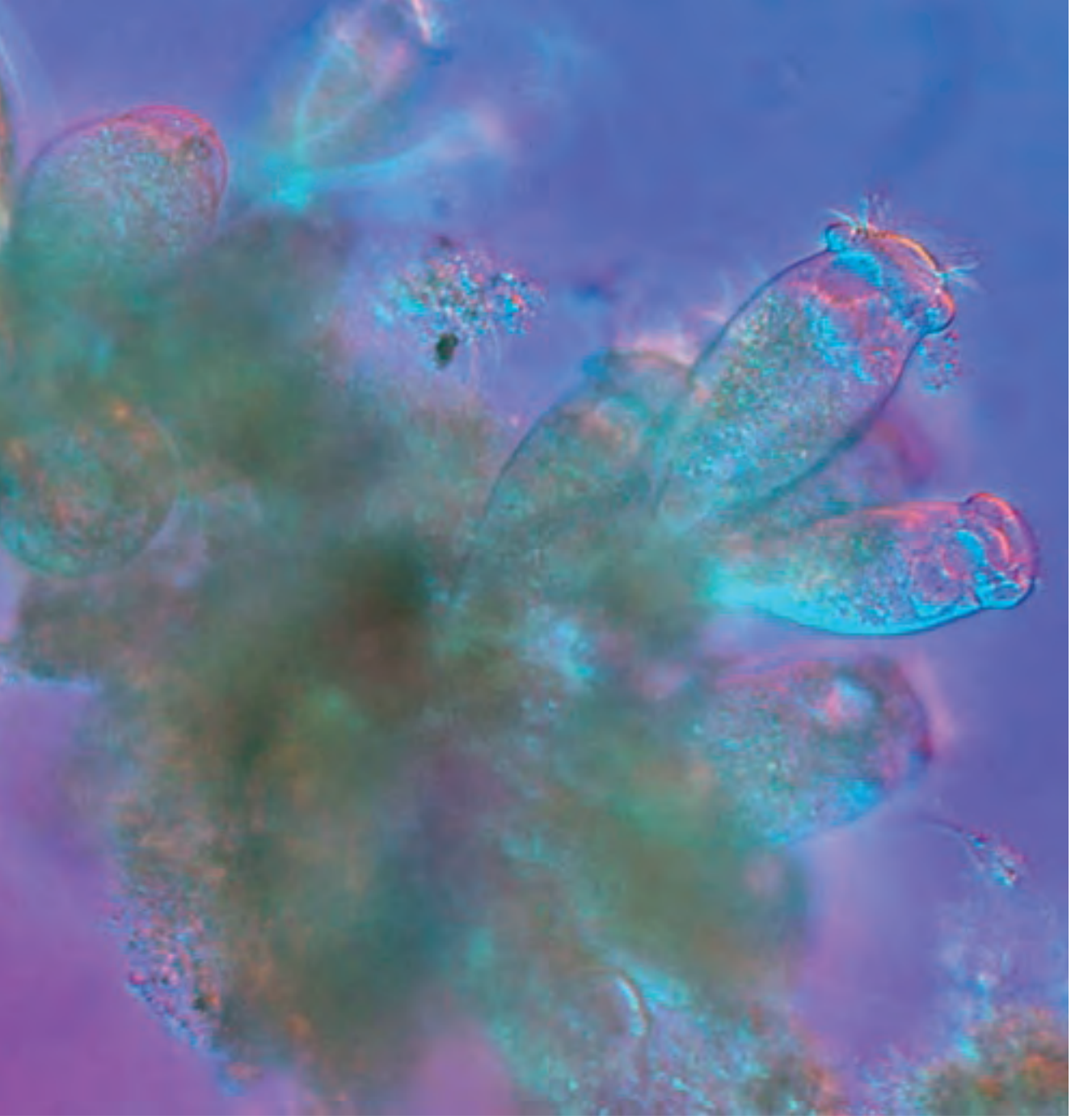
Microbiological treatment of used water for the protection of public health and the aquatic environment

Mike Dempsey

Historical aspects

Development of treatment processes and conveyance systems for drinking water and sewage by Manchester Corporation towards the end of the 19th century was pivotal in breaking the cycle of water-borne disease in the world's first industrial city. Conveyance of sewage to the Davyhulme treatment works resulted in the reduction of both microbial contamination and rat populations in the city. Contamination with *Vibrio cholerae* or *Salmonella typhimurium* could cause cholera or typhoid in anyone drinking infected water drawn from wells or streams. Rats carry disease and fleas, which can be infected with *Yersina pestis*, the causative agent of bubonic plague.

The trickling filter (TF) process for sewage treatment was first used in Salford in 1893 and the activated sludge (AS) process was developed at



Protozoa attached to biofilm from an expanded bed biofilm reactor used for nitrification of activated sludge settled effluent. Mick Hoult

Davyhulme in 1914. The TF technology was commercialised by the pioneering Manchester engineering company Mather and Platt. And the AS process was developed by Fowler, Ardern and Locket while members of the Manchester Corporation Rivers Department. These two treatment processes are now used worldwide, which has resulted in widespread improvements in human and environmental health.

Recently, innovation of processes for used water treatment has moved abroad, especially to the Netherlands where Delft Technical University has pioneered processes associated with nutrient removal, for example. This change in location of innovation is often considered to be an unforeseen consequence of privatising the UK water industry, and the risk-averseness engendered by the necessary joint regulation of prices and environmental protection imposed by the UK government.

Metabolism and ecology

Politics aside, the purification of used water occurs mainly through the joint metabolic activities of protists, bacteria and archaea. Protists, such as protozoa and rotifers, are largely responsible for the removal of pathogens, through either filter-feeding or grazing. For example,

in the 1970s, a UK study demonstrated that protozoa in the AS process were responsible for filtering the water 10 times as it passed through this process. These eukaryotic microbes are also important in maintaining system health, through control of the benign, prokaryotic microbial populations, namely the mixed bacterial or archaeal communities involved in the various treatment processes.

Nowadays in the UK, on average, each person uses about 150 litres of water per day. After use, this water must be cleaned before it is returned to the aquatic environment, so that public health and aquatic organisms are protected. Complex communities of heterotrophic bacteria are responsible for reducing aquatic pollution through mineralisation of nutrients following metabolism of the complex organic matter found in sewage. Otherwise, excessive growth of similar microbes in the receiving water would lead to anoxia, the death of fish and further degradation of the waterway.

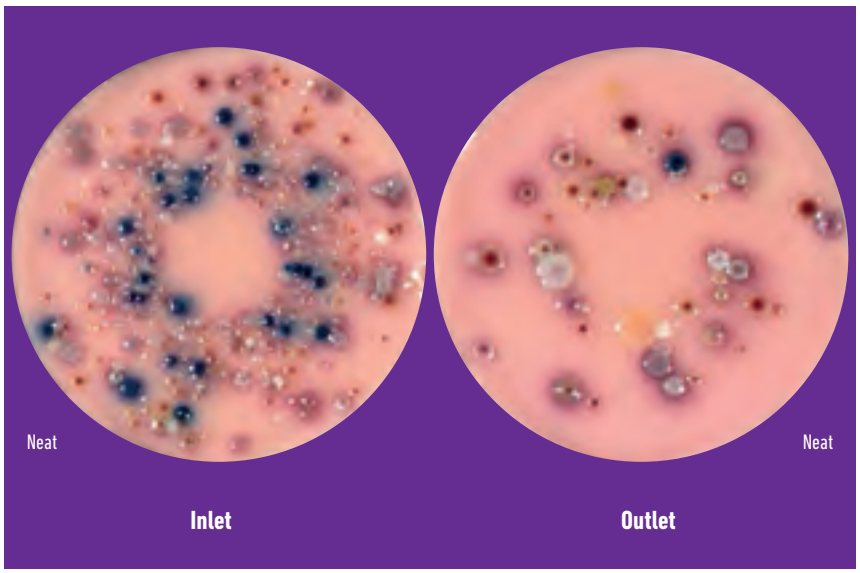
The technology is designed to allow microbial growth processes to treat the water we use in the home and industry so that it is clean enough to be returned to the aquatic environment, where natural processes complete its purification.

Phosphorous and nitrogen cycles

Heterotrophic bacteria are also essential for a phosphate-removal process that is more sustainable than older processes involving chemicals for its precipitation, prior to removal by sedimentation. Phosphate is an essential plant nutrient but, unless it is removed, eutrophication of the receiving water can result in excessive growth of cyanobacteria, algae and other photosynthetic protists, such as dinoflagellates. These organisms can cause unsightly blooms, many of which are toxic to other organisms. The poisoned organisms are mostly aquatic but can include humans consuming contaminated aquatic organisms, as well as animals drinking contaminated water.

Especially when nitrate is absent or at low concentration, cyanobacteria fix nitrogen and thus thrive in phosphate-enriched waters, as demonstrated in the Experimental Lakes Area study in Canada. This led the Canadian authorities to impose strict discharge limits on phosphate but not nitrate, which can help to keep phosphate locked up in sediments. The rest of the developed world has followed Canada's lead on strict controls on phosphate removal but has yet to follow its science-informed lead of allowing nitrate to be discharged to reduce the potential release of phosphate from sediments.

Two groups of autotrophic bacteria are responsible for oxidising potentially toxic ammonia to relatively safe nitrate, namely the ammonia and nitrite oxidisers. Ammonia is released from organic matter mainly during deamination of amino acids by heterotrophic bacteria, and is not usually fully nitrified in conventional TF and AS processes because the nitrifiers are slow-growing and cannot compete for oxygen with the heterotrophs. Therefore, a separate process is often used to allow complete nitrification, especially



Inlet and outlet concentrations of bacteria growing on chromogenic medium (Oxoid) for identification of coliforms (blue colonies are *Escherichia coli*; red colonies are other coliforms). Inlet was undiluted activated sludge settled effluent; outlet was undiluted effluent from an expanded bed biofilm reactor for tertiary nitrification. Maha Mustafa and Inaee Porto

Trickling filter (TF) with traditional stone packing, typically used at small rural works. Mike Dempsey

Activated sludge (AS) zone, empty to show surface paddle for aeration. Mike Dempsey

at large works with high ammonia loads. In contrast, heterotrophic bacteria are used in conventional denitrification, for removal of nitrogen from the aquatic environment. Here, nitrate is used as the terminal electron acceptor in anoxic respiration, so that nitrogen gas is returned to the atmosphere.

Microbiology informs engineering

Research at Wageningen Agricultural University in the 1980s led to the discovery that three groups of microbes were largely responsible for anaerobic digestion: hydrolysers, liquefiers and methanogens. In turn, this led to engineers developing a two-stage process that reduced the time required for anaerobic digestion. The hydrolysers and liquefiers were mostly responsible for activity in the first stage, and methanogens for the second stage. More recently, engineers have developed multi-step processes for anaerobic digestion, including a thermal hydrolysis step that effectively 'cooks' the organic matter, thus making it more available to the microbes.

In the 1970s, a microbial ecologist contended that there ought to be a group of microbes that oxidise ammonia using nitrate, effectively a short-cut of the nitrogen-cycle predicted from thermodynamics. Observation in the late 1980s of an unusual, deep-red biofilm in a fluidised bed bioreactor treating wastewater at a Gist-Brocades factory in Delft eventually led to the identification of a new group of *Planctomyces* bacteria by a group of microbiologists at Delft University of Technology. Engineers have developed processes using these anammox (anaerobic ammonium oxidation) bacteria for denitrification that use less energy for aeration in a partial nitrification step and have no requirement for organic carbon for denitrification, thus saving considerable costs.

Recent work at the Advanced Water Management Centre, University of Queensland, identified a new bacterium capable of accumulating phosphate to high levels. This bacterium, '*Candidatus* Accumulibacter phosphatis' is now used in new phosphate-removal processes.

Process technology

Biological treatment of used water begins with separation of solid from liquid waste, through sedimentation of a primary sludge. The liquid waste is aerated so that protists can consume pathogens and particulate organic matter, whilst heterotrophic microbes grow on the dissolved organic matter. These microbes are sedimented as a secondary sludge and combined with the primary one, often for anaerobic digestion. The clarified water is then either discharged or further treated to nitrify, denitrify or remove phosphate, depending on local conditions. Essentially, the technology is designed to allow microbial growth processes to treat the water we use in the home and industry so that it is clean enough to be returned to the aquatic environment, where natural processes complete its purification.

Future prospects

Continued research to identify the micro-organisms involved in biological processes for treatment of used water and to investigate their metabolism will lead to further development of new processes in collaboration with process engineers. Furthermore, development of more sustainable, lower-cost processes will help us to achieve the UN's Millennium Development Goals of reducing global poverty by making biological treatment of used water more affordable.

Mike Dempsey

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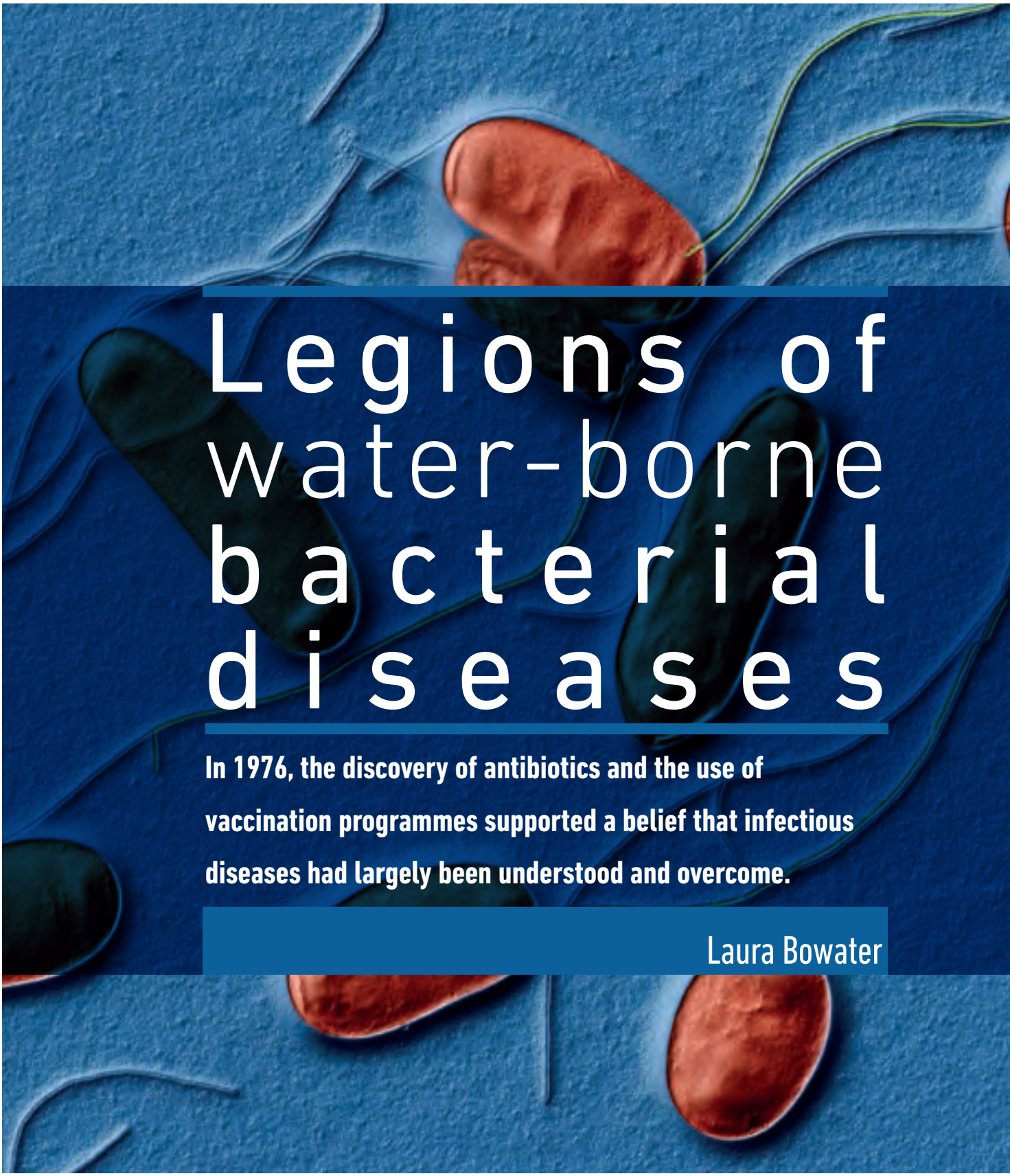


Legions of water-borne bacterial diseases

In 1976, the discovery of antibiotics and the use of vaccination programmes supported a belief that infectious diseases had largely been understood and overcome.

Laura Bowater

False-coloured scanning electron micrograph (SEM) of *Legionella pneumophila* bacteria. Eye of Science / Science Photo Library

1976 held a special significance in the USA as the country celebrated the bicentennial anniversary of the signing of the 4 July Declaration of Independence. More than 2,000 members of the Pennsylvanian American Legion of war veterans celebrated this historic event during their annual three-day convention at the Bellevue-Stratford Hotel, Philadelphia on 21–23 July. Then nearly two weeks later, the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia was alerted to the deaths of four veterans who had died from suspected pneumonia after attending the convention. Subsequently, with an incubation period of 2–10 days, a cluster of cases followed with reported symptoms of a mild cough, fever and, in some people, a progressive pneumonia that led to death. By the end of the epidemic, 182 members of the legion were diagnosed and 29 fatalities reported. In addition, another 39 people who had been in the close vicinity of the hotel developed a similar disease that caused another five deaths.

In many ways this outbreak marked a turning point in disease surveillance as it became apparent that 'new' infectious diseases would continue to be identified and a state of readiness was vitally important. The CDC began to track down the cause of this infection. The key risk factors for the illness were found to include old age, being male and being a smoker, as well as spending time in the lobby or outside the front door of the hotel. There was negligible evidence to suggest the disease was associated with food or person-to-person spread and it became clear that this was an air-borne infection. However, it was nearly six months after the outbreak before the perpetrator of the disease was identified, the bacterium *Legionella pneumophila*.

Identifying the disease

Tantalising clues about the cause of the disease had emerged. For example, in laboratory tests using eggs inoculated with infected lung tissue from the diseased victims, several of the eggs died because of so-called 'bacterial contamination'. Also, guinea pigs that were inoculated with infected human tissue became ill, but the diseased guinea pig tissue could not transmit the infection to other guinea pigs.

Joseph McDade was the scientist whose initiative, persistence and previous experience with *Rickettsia* allowed him to follow the clues. In late December 1976, McDade decided to re-examine slides, stained for bacteria, taken from guinea pigs that had died after he had inoculated them with diseased material earlier that year. Eventually he spotted a small cluster of Gram-negative bacilli. Rather than dismissing them as bacterial contamination, he isolated them as if they were the *Rickettsia*. The confirmation that these were the disease-causing bacteria came when the sera of patients from the Philadelphia outbreak gave a positive antibody-mediated response to the isolated bacteria. Legionnaires' disease and its newly associated pathogenic bacteria, *L. pneumophila*, had been found.

Legionella, a new bacteria?

L. pneumophila was quickly associated with a raft of subsequent outbreaks of community- and hospital-acquired pneumonia. However, it also provided

American bacteriologists Drs Joseph E. McDade (left) and Charles C. Shepard (right), who isolated and identified the bacteria which causes Legionnaires' disease. CDC / Science Photo Library

Table 1. Comparison of the two syndromes associated with *L. pneumophila* infection

Legionnaires' disease	Pontiac fever
Mild cough to fatal pneumonia. Death is an outcome of respiratory, kidney and/or multi-organ failure	Acute self-limiting influenza-like illness. Symptoms usually last 2–5 days but the disease is not fatal.
Incubation period: 2–16 days	**Incubation period:** up to 48 hours
Symptoms: fever, anorexia, headache, lethargy, muscle pain, diarrhoea and confusion. Blood-streaked phlegm can also occur in some patients.	**Symptoms:** fever, chills, headache, sore muscles and joints.

fresh insight into previous disease outbreaks of unknown origin, including an outbreak of a respiratory disease that had affected workers and visitors to a health department in Pontiac, Michigan, USA, eight years previously. Unlike the symptoms of *Legionella*, the subsequently named Pontiac fever is an acute self-limiting disease with a short incubation period and flu-like symptoms (Table 1). To date, it is still not clear why infection with *L. pneumophila* causes two distinct syndromes as a result of inhalation of contaminated aerosols produced by man-made water systems, including cooling-towers, showers, air-conditioning systems, hot tubs, and occasionally through direct placement of *L. pneumophila* into the lungs during respiratory tract manipulations.

So where had this infection come from?

L. pneumophila is just one of more than 50 species and 70 serogroups of *Legionella* that have since been isolated. Only a small fraction of these species cause human infection, but this includes *Legionella longbeachae*, a soil-borne pathogen that causes disease through exposure to aerosols formed from commercial potting compost. *Legionella* are Gram-negative, non-spore-forming, flagellated bacilli, which are ubiquitous in freshwater systems, including lakes, rivers and thermal springs. However, Legionnaires' disease is not associated with exposure to the bacteria from these natural environments. It is man-made water systems with a temperature range between 20 and 42 °C that provide favourable conditions for bacterial growth. The stagnant water and low water pressure associated with hotels, ferries and cruise ships has also ensured that travel has been identified as a risk factor for Legionnaires' disease. *Legionella* have been shown to survive temperatures of 54 °C, and below 20 °C as the bacteria hibernate while they wait for conditions that are more favourable for growth.

Legionella as parasites

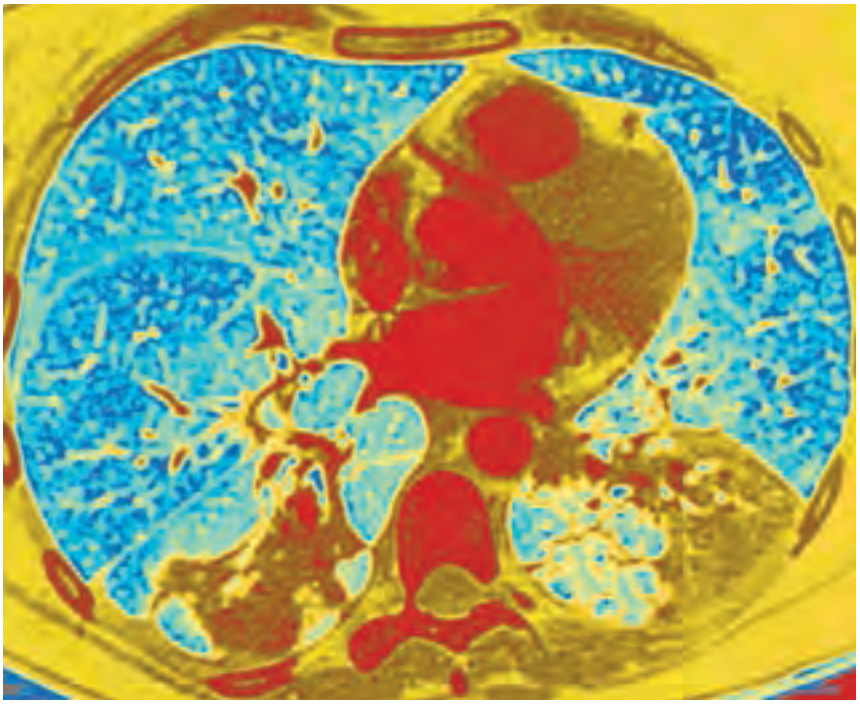
The life of bacteria in the environment is very different to their cultured laboratory life. Microbes can exist in assembled, complex communities with shared survival mechanisms. These include essential intracellular communications, which are key for the survival of microbes in environments such as domestic water supply systems that are low in nutrients. Biofilms develop on surfaces of stagnant or undisturbed non-sterile water and have been shown to be the concentrated source of micro-organisms in this environment. *Legionella* form part of these water-borne biofilms that can be notoriously hard to remove from the surfaces of man-made water systems. These biofilms can also contain a large variety of protists that include amoeba and ciliated protozoa.

A large number of free-living protozoa have been shown to host *L. pneumophila*, providing ready access to a range of free nutrients that allow *Legionella* to obtain the nutrients and energy supply they need to replicate. *Legionella* that have been associated with other organisms, such as protists, have been found to be more pathogenic to humans. When the bacteria are engulfed or phagocytosed by the protozoa they are housed within the *Legionella*-containing vacuole (LCV). An elegant survival trick by the bacteria is

The long association between *Legionella* and protozoa has led to the transfer of a suite of advantageous genetic elements to the bacteria. These have enabled the bacteria to acquire effector molecules that allow them to adapt to the intracellular environment of the protozoa.

that they ensure the LCV manages to avoid being targeted by the intracellular lysosomes that contain the hydrolytic acidic environment that usually degrades and removes engulfed invasive bacteria. Instead, the bacteria use mechanisms that allow the cellular LCV to change its membrane structure, disguising itself as part of the normal cellular organelle, the endoplasmic reticulum. This ensures that the LCVs that contain the bacteria avoid being targeted by the cellular lysosomes.

Interestingly, the mechanisms that *Legionella* employ to evade destruction in humans are similar. The bacteria replicate in LCVs contained in the alveolar macrophages where they evade destruction, but also convert the normal cellular processes of the macrophages to produce short peptides and amino acids. *Legionella* convert cysteine and serine to pyruvate, which is fed into the TCA cycle to generate the major sources of carbon and energy required by the bacteria to survive and replicate. The long association between *Legionella* and protozoa has led to the transfer of a suite of advantageous genetic elements to the bacteria. These have enabled the bacteria to acquire effector molecules that allow them to adapt to the intracellular environment of the protozoa. Subsequent man-made manipulation of the natural environment generated new water systems that allowed aerosols of these bacteria, including *L. pneumophila*, to be generated and inhaled. This in turn allowed the bacteria to use the skill set it acquired from cohabitation with protists to adapt to life within human phagocytes. Once inside human cells *L. pneumophila* is able to delay apoptosis (programmed cell death) of the macrophages, allowing the bacteria to proliferate within the cell before they are released to infect other cells.



False-coloured axial computed tomography (CT) scan of the lungs (blue/green) of a patient with Legionnaires' disease. The infection (yellow, lower right and left) is a severe form of pneumonia. ISM / Science Photo Library

The good news

As long as there are man-made water supplies *Legionella* presents an environmental health risk that needs to be avoided. There are physical steps that can be taken to help prevent *Legionella* contamination. These include reducing the risks of water stagnation, and ensuring the temperature of cold water is kept below 20 °C and hot water is kept above 50 °C (although not scalding). Better legislation, for example, monitoring the potential sources of *Legionella* infection such as in water towers, has lead to a reduction in the opportunities for infection. Secondly, employing guidelines to reduce bacterial viability using, among other steps, halogenation and monitoring can eliminate *Legionella* detection from man-made water systems. Surveillance and education programmes will both have their part to play in ensuring that outbreaks of Legionnaires' disease are avoided in the future.

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Further reading

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Conferences

Annual Conference

30 March–2 April, ICC, Birmingham, UK

The 2015 Annual Conference will feature a range of scientific sessions titled:

- Antimicrobial resistance
- Clostridia – the good, the bad and the beautiful
- Microbes in space
- Microbial archaeology
- Microbiome in health and disease
- Mitochondria and related organelles in microbial eukaryotes
- Natural and unnatural virus evolution
- Sensory perception in microbes: coping with change
- The building blocks of microbial evolution
- The rhizobiome
- Virus assembly – let's get together and get out of here

Virology workshops will include:

- Antivirals and vaccines
- Clinical virology
- Evolution and virus populations
- Gene expression and replication
- Innate immunity
- Pathogenesis
- Plant virology

The conferences are a welcoming and supportive arena to discuss work. Small enough not to intimidate, but large enough to attract big names and get really useful feedback. Erin M

In addition, the conference will feature a number of prokaryotic forums that will cover four broad areas of prokaryote biology, including infection, genetics, cell biology and environmental microbiology.

All sessions are listed on the Society's website: **www.sgm.ac.uk/conferences**

2015

Call for abstracts

Abstracts are invited from all areas of microbiology for presentation at the conference as either offered papers or posters.

Most sessions have space for offered orals, and all welcome poster abstracts. Poster presentation sessions will take place on the Monday, Tuesday and Wednesday evenings during the conference.

Details on how to submit your abstract, via the online system, are available on the Society's website: **www.sgm.ac.uk/conferences**

The deadline to submit an abstract is **Monday 19 January 2015**.

Don't forget, if you would like to be considered for the Sir Howard Dalton Young Microbiologist of the Year Competition please indicate this when submitting your abstract.

Focused Meeting proposals invited for 2015 and 2016

To widen the scope for members to further contribute to the scientific content of the Society's conferences, there is an opportunity to submit proposals for Focused Meeting topics for 2015/16. Focused Meetings can be on any area of microbiology and full secretariat support will be provided by the Society. Details on how to submit your proposal are available on the website: **www.sgm.ac.uk/conferences**

The deadline to submit your proposal is **15 December 2014**.

Irish Division Meeting 2015

17–19 June

University of Galway, Ireland

The Irish Division Meeting 2015 is titled *Microbial Interfaces* and will include sessions on the following topics:

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

Abstract submissions will open in **October 2014**.

Quadrangle in Galway. iStock/ThinkStock

New manuscript submission sites launched for all Society for General Microbiology journals

The Society for General Microbiology (SGM) has begun using a new journal manuscript submission and tracking system, Editorial Manager. The Society has also launched ProduXion Manager, a new production tracking system. Both are provided by Aries Systems.

Benefits to SGM authors include:

- Streamlined submission system with modern features
- Clear user interfaces which are easy to navigate
- Improved review process - users indicate their areas of expertise so reviewers can be assigned quickly
- Transparent manuscript tracking system - view the status of your article from submission through to publication

All existing users have been securely moved to the Aries platform from our previous Bench>Press submission system. Users should have received an email informing them of the move to the new system, and when logging in they may be asked to update their profile to include new information.

New users will need to register and set up their profile.

Please direct any queries about the move to Editorial Manager to journals@sgm.ac.uk.

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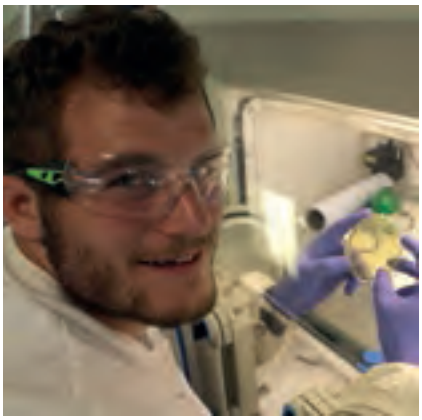
SOCIETY FOR GENERAL MICROBIOLOGY

Membership Q&A

Peter Rowe



Where are you currently based?

The GASCHEM (optimising GAS fermentation for the production of sustainable CHEMicals) team in University of Nottingham's Clostridium Research Group.

What is your area of specialism?

Microbial fermentation and metabolic engineering.

And more specifically?

I work with *Clostridium autoethanogenum*, an anaerobic acetogen capable of gas fermentation. This organism has huge potential in the field of renewable energy as it can use gases rich in carbon monoxide, carbon dioxide and hydrogen as sole carbon and energy sources. It is capable of producing a range of commodity chemicals, including ethanol, acetate and 2,3-butanediol. This organism has been proven to produce such chemicals using industrial waste gas as a feedstock, and therefore can simultaneously reduce waste gas emissions and produce valuable chemicals.

Currently, genetic engineering tools available for the *Clostridium* genus are far behind those available for other organisms. My role within the team is to develop new tools for genome editing and metabolic engineering applications, with the aim of increasing the yield and range of chemicals produced by *C. autoethanogenum*.

Tell us about your education to date

I graduated last summer from the University of Manchester with a degree in Biotechnology with Enterprise. This included a year-long internship placement at AlerGenetica, a biotech start-up specialising in developing treatment for fungal allergies. There I worked on developing a strain of *Aspergillus niger* capable of secreting heterologous proteins at high titres.

Where did your interest in microbiology come from?

For me, human and plant biology is based around something very tangible that you can see and feel. I think microbiology has a greater level of intrigue because it is the study of something that in most cases you barely notice is there.

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

Currently, I'm working on implementing a few new techniques that nobody else in the research group has worked on. I try and overcome the problems presented by these by thoroughly researching how similar techniques have been applied in other fields and luckily I've got a great team of people to talk through my problems with.

What is the best part about 'doing science'?

I like the idea that I can find out some interesting things that nobody else has ever done.

Who is your role model?

When I was growing up it was Jonny Wilkinson, but in terms of science I'd have to say Craig Venter.

What do you do to relax?

Mostly sports, I play rugby, football and cycle a lot. I also really enjoy travelling when I have the free time, for instance I spend a couple of weeks this year hiking around Norway's national parks.

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

For the record I would choose High Violet by The National. In terms of a luxury item I'd probably opt for a cafetière with an abundant supply of good coffee.

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

I have an irrational fear of cows.

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

I'd like to think I would be doing something to do with sports and travelling, perhaps a ski instructor?

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

Society membership – more than meets the eye

With membership renewal season just around the corner, we want to ask you a very important question; are you getting the very best you can from your association with us?

You may have joined originally to take advantage of a grant or because a colleague suggested it. They are both sound reasons; but once in, members often find there are many more reasons for joining they were not previously aware of.

One of the recurring benefits members cite is the Society's ability to create great networking opportunities – chances to catch up with old friends, make new ones, sound out a research grant or a new job. Our conference, Focused Meetings, committees and workshops are excellent ways to do all of these; and all in a supportive and encouraging environment. There are many more benefits. Take a look below to see how others are making the most of their membership. We hope it provides inspiration for you too.

"Society conferences provide excellent opportunities for me to meet up with both current and potential future collaborators."

Rocky Cranenburgh, Member

Our Annual conference offers exceptional opportunities to network, catch up and share experiences (the next one is in Birmingham, April 2015 – diary it now).

"Membership gives me great access to new information."

Sabine Lichtenegger, Member

Learn more. Check out our blog, website, members' magazine articles and events. Our journals too have great impact factors.

Society membership gives me very good networking opportunities.

Hajah Mohd Afsar, Member

We run two Focused Meetings on specific topics and many other meetings during the year. Check the dates on our website. These are great networking opportunities.

The Society for General Microbiology is internationally renowned.

Kunda Musonda, Member

Use our reputation to enhance yours.

The Society for General Microbiology – it's the best place to present your work!

George Russell, Member

Share your research findings. Present a poster or a paper; submit an article to our Journals (where we offer a 15% discount on the open access fee rate).

I like it so much I've become involved in a number of committees and organising symposia.

Petra Oyston, Member

Develop new skills to enhance your CV and make the most of your experience.

As you can see, many members already take full advantage of what membership has to offer. Why not join them?

Membership renewal time is coming

In this issue of *Microbiology Today* you will find an A4 poster promoting the Society and the benefits of membership. If you work with others could you help us out by displaying this in your workplace? It's a little thing that could make a big difference. We are keen to spread the word and encourage more members to join. More members mean we can do even more for you.

Also in this issue is a direct debit form. Members who renew via direct debit help us by reducing our administrative costs. These members also qualify for discounted subscription rates too! When you receive your renewal email or letter in the coming weeks, please consider renewing via direct debit. Just complete the enclosed form and return it to us. Remember though – we need the original form (no copies, or scanned versions).

Paul Easton
Acting Head of Membership Services
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Schoolzone

Bioluminescence

Centuries ago, in a time of myths of dragons and gods, seafarers and beach dwellers were baffled by the flashes of light and glowing lights seen in oceans all over the world. Today, we now know this is caused by bioluminescence, a chemical emission of light seen across the tree of life, in fish, invertebrates, annelids, arthropods and, most interestingly for us, micro-organisms.

Bioluminescence in the sea at Black Point, Anglesey. Kris Williams

The blue-green light seen at the surface of oceans is bioluminescent microbes. Light is produced from a class of substrates called luciferins, in an oxidation reaction catalysed by the enzyme luciferase. In bacteria, this reaction is controlled on the *lux* operon and in other microbes bioluminescence occurs in organelles called scintillons.

Dinoflagellates

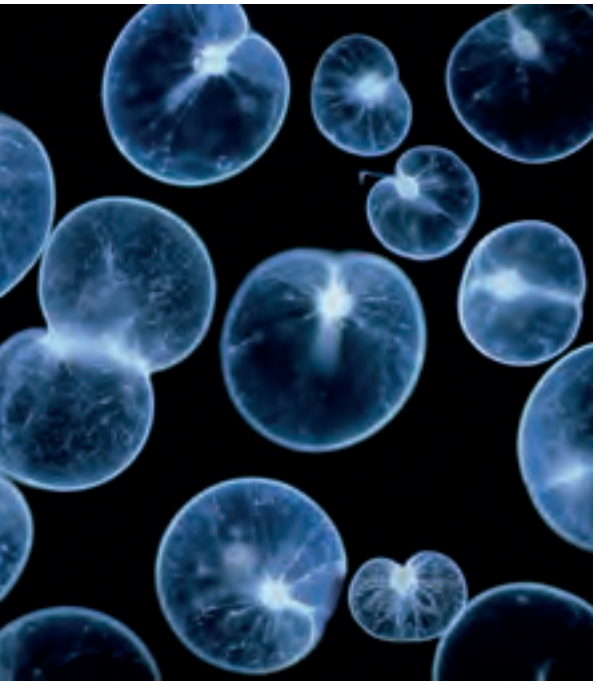
Much of the bioluminescence seen on the ocean surface is from the unicellular algae dinoflagellates. They are responsible for some of the most impressive displays of bioluminescence, and attract tourists to bays and lagoons in places such as Puerto Rico, Jamaica and the Maldives.

Dinoflagellates are protists that live mainly in seawater. They comprise around 18 genera that are capable of bioluminescence, all of which contain scintillons, organelles that contain luciferase and luciferan. Bioluminescence in dinoflagellates is so vital that more energy is put into emitting light than into growth. They use bioluminescence as a distraction or to surprise predators.

In dinoflagellates, bioluminescence occurs on a circadian rhythm, with light only being emitted at night. Unlike bacteria and fungi, the light is emitted in flashes and occurs because of a physical disturbance to the cell, such as boats and wave movement. Common dinoflagellates include *Noctiluca scintillans*, known as 'Sea Ghost'. *Pyrodinium bahamense* is found in tropical waters of the Atlantic and *Lingulodinium polyedrum* in warm coastal waters including the Pacific.

Bioluminescent fungi

There is only one order of fungi that contains species that can bioluminesce: the Agaricales. Depending on the species, light can be emitted from mycelia, fruiting bodies or spores. Unlike dinoflagellates, they emit light continuously. There is a lot less understanding of bioluminescence in fungi than in bacteria or dinoflagellates, but the mechanisms are similar in the use of luciferin and luciferase and the emission of blue-green light. Fungi's ability to bioluminesce is thought to be linked with metabolism, as variables such as pH, light and temperature affect bioluminescence in Agaricales species. The purpose behind fungal bioluminescence is not fully understood, but suggestions are that bioluminescent fruiting bodies could promote spore



The dinoflagellate *Noctiluca scintillans*. Wim Van Egmond / Visuals Unlimited, Inc. / Science Photo Library

dispersal by attracting grazers, and that, conversely, bioluminescent mycelia could deter grazing and thereby act as protection against predators.

Bioluminescent bacteria

The majority of bacteria with bioluminescent capabilities are from the family *Vibrionaceae*, with some species occurring in the genera *Photobacterium* and *Photorhabdus*. Mostly found in marine environments (water, sediment, the surface of decomposing fish and the guts of marine animals), they can be free-living, or live in symbiosis with larger organisms, such as squid or nematodes. Symbiotic bacteria allow the symbiont to use their bioluminescence for predation and attracting a mate in exchange for available nutrients. Free-living bacteria are thought to use bioluminescence in quorum sensing, a mechanism by which bacteria regulate gene expression in accordance with population density through the use of signal molecules.

'Milky seas', or 'mareels', is the name given to the effect of bioluminescent bacteria turning up to 6,000 square miles of ocean into a glowing light show.

Using bioluminescent microbes in schools

It is quite easy to grow certain species of bioluminescent dinoflagellates in schools. *Pyrocystis lunula* is a robust and easily grown dinoflagellate that can be purchased cheaply from a variety of culture collections, such as the Culture Collection of Algae and Protozoa. Information on how to grow and keep these microbes in a classroom can be found on their website: **http://microb.io/1o7GocG**

Dinoflagellates bioluminesce in a circadian rhythm. To use in a classroom environment, their day/night growing patterns must be reversed. This can be achieved by growing them in a windowless room with an artificial light on overnight for 12 hours, and then keeping them in darkness for 12 hours during the day. The microbes will then bioluminesce during their 'night phase', when everyone is in school. It usually takes a week for the dinoflagellates to readjust to their new light schedule.

Theresa Hudson

Education and Outreach Officer

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Further reading

Culture Collection of Algae and Protozoa. **http://microb.io/1o7GocG** – *last accessed 10 October 2014.*

As well as being a fun and eye-catching microbe to use in schools, there are many interesting experimental questions that can be asked about dinoflagellates.

Dinoflagellates bioluminesce when mechanically agitated:

- What stimulations cause them to flash?
  - How rough does the disturbance have to be?
  - How many times can they be disturbed before they can no longer bioluminesce?
  - How long does it take for them to recover?
- What immediate effects do you see if you put dinoflagellates in their night phase into the light?

Investigations using a basic light microscope:

- What differences do you notice between a cell in the middle of its day phase and one in the middle of its night phase?
  Hint: The chloroplasts are the golden-brown bodies within the cell. How might you explain this?
- Examine the different stages in the life cycle of these asexually reproducing cells (the entire life cycle takes 5–7 days).

Bioluminescence has been used in a variety of biotechnology products, including the potential to create bioluminescent *Escherichia coli* bacteria to be used in light bulbs.

- What other technologies could bioluminescence be used in?

Outreach

Royal Society Summer Science Exhibition 2014: Leafcutter ants and their antibiotics

My research group had the privilege of presenting our research at the prestigious Royal Society Summer Science Exhibition 2014. This week-long event is completely free to schools and the general public and is hosted in the beautiful Royal Society building, just off The Mall and around the corner from Trafalgar Square.

Our display was entitled *Leafcutter ants and their antibiotics* and included a live leafcutter ant colony, an antibiotic discovery zone, as well as an animation explaining the research and a 3D leafcutter ant which you can see on the University of East Anglia website: **www.uea.ac.uk/leafcutter-ants**

We were one of about 20 exhibits selected from more than 100 applications, only two of which were related to microbiology. Leafcutter ants and their close relatives are amazing microbiologists and have been culturing a fungus as the sole food source for their colonies for more than 50 million years. They feed this fungus leaf material that they cut from the rainforest canopies in South and Central America and they tend their fungus gardens just like human farmers tend their crops. They groom and weed out other unwanted microbes and protect themselves and their fungus against diseases by growing antibiotic-producing bacteria on their cuticles. They feed these bacteria through specialised glands and in return the bacteria provide them with antibiotics to use as weed killers in their fungus gardens. Remarkably, they use the same type of soil bacteria – known as actinomycetes – that provide us with 80% of the antibiotics used in human medicine but the ants have been doing it for much, much longer and have no problems with drug resistance. We have been exploring this unique environmental niche for novel antibiotics and also using leafcutter ants as an experimental model to try and understand how beneficial microbiomes form. The ants have also provided us with a fantastic outreach tool for explaining how antibiotics are used in nature.

We had an absolutely amazing time at the Royal Society and the response from the general public was terrific. It was inspiring to meet such enthusiastic and engaged members of the public, with around 15,000 visitors attending the event. We were also very lucky to be in London the same week that David Cameron made his announcement about the dire need for new antibiotics. In possibly the strangest night of my life, I was chauffeured to BBC Broadcasting House to talk to Eddie Mair about antibiotics on the Radio 4 *PM* programme and then chauffeured back again with just enough time to get into my tuxedo and dash to the VIP evening soirée at the Royal Society. Things got even more surreal the next day when a film crew from the BBC's *The One Show* turned up to make a film about our leafcutter ant exhibit. It was great to share our love for microbiology, and I hope that more Society members will apply to have exhibits at Summer Science in 2015.

I'd like to thank everyone that visited us there, the amazing team of scientists that worked hard all week on our stand, and everyone else who offered support in getting the exhibit together. The Society, and in particular Benjamin Thompson, Theresa Hudson and Dariel Burdass, also deserves very special thanks for very generously helping to fund and support the exhibit and for providing lots of great microbiology materials for us to give away to the general public. The next public appearance of our leafcutter ants will be at the BBSRC Great British Bioscience Festival in November at the Museum Gardens in London's Bethnal Green. We'll be part of the *Antibiotic Hunters* exhibition with our collaborators at the John Innes Centre in Norwich.

Matt (left) with members of the group at the University of East Anglia stand.

Matt Hutchings
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International signalling:

a PhD student's report from the third Young Microbiologists Symposium

On 2 and 3 June this year I was lucky enough to attend the Young Microbiologists Symposium (YMS) at the University of Dundee sponsored in part by the Society for General Microbiology. This was an international conference aiming to bring together young and early career microbiologists organised by members Robert Ryan and Sarah Coulthurst from the University of Dundee.

Alexander Westermann (Institute for Molecular Infection Biology, Würzburg) asking one of the keynote speakers a question.
John Allan

This year the meeting carried the themes of microbial signalling, organisation and pathogenesis. Each of the five sessions were opened by a renowned expert in the area of the designated session with the rest of the talks given by a mixture of junior principal investigators, postdoctoral fellows and PhD students.

The conference kicked off with the EMBO-sponsored lecture by Urs Jenal from the Biozentrum at Universität Basel. Professor Jenal delivered an elegant and entertaining talk describing the role of the intracellular second messenger molecule cyclic di-GMP in the development and life cycle of *Caulobacter crescentis*. Resonances of the theme of cyclic di-GMP and intracellular signalling were carried forward throughout the morning session and indeed much of the conference.

In the afternoon session on host–microbe interactions, Sophie Helaine, a starting Principal Investigator from Imperial College London gave a fascinating talk on her model for identifying replicating and non-replicating *Salmonella typhimurium* cells living inside macrophages by using fluorescent markers that designate bacterial generations. In the same session was Alexander Westermann, a PhD student from Professor Jorg Vogel's group in Würzburg, who gave a talk on his work looking at the transcriptomes of pathogen and host cells during infection using dual RNA sequencing.

On the second day, in the first session on cellular development, Lotte Søgaard-Andersen from Philipps-Universität in Germany set the tone with a talk on cell morphogenesis in *Myxococcus xanthus*, an organism well known for activating a multicellular developmental programme in response to starvation. Another enlightening talk in the same session was given by Rut Carballido-López from INRA in France, who discussed, among other things, the work in her lab to gain a detailed understanding of how the actin-like protein, MreB, gives bacteria shape.

A vast selection of posters were also on display covering a wide variety of topics, from surveys of the microbiota associated with plant tissues to synthetic biology approaches for biohydrogen production to metabolic adaptation of *Clostridium difficile*.

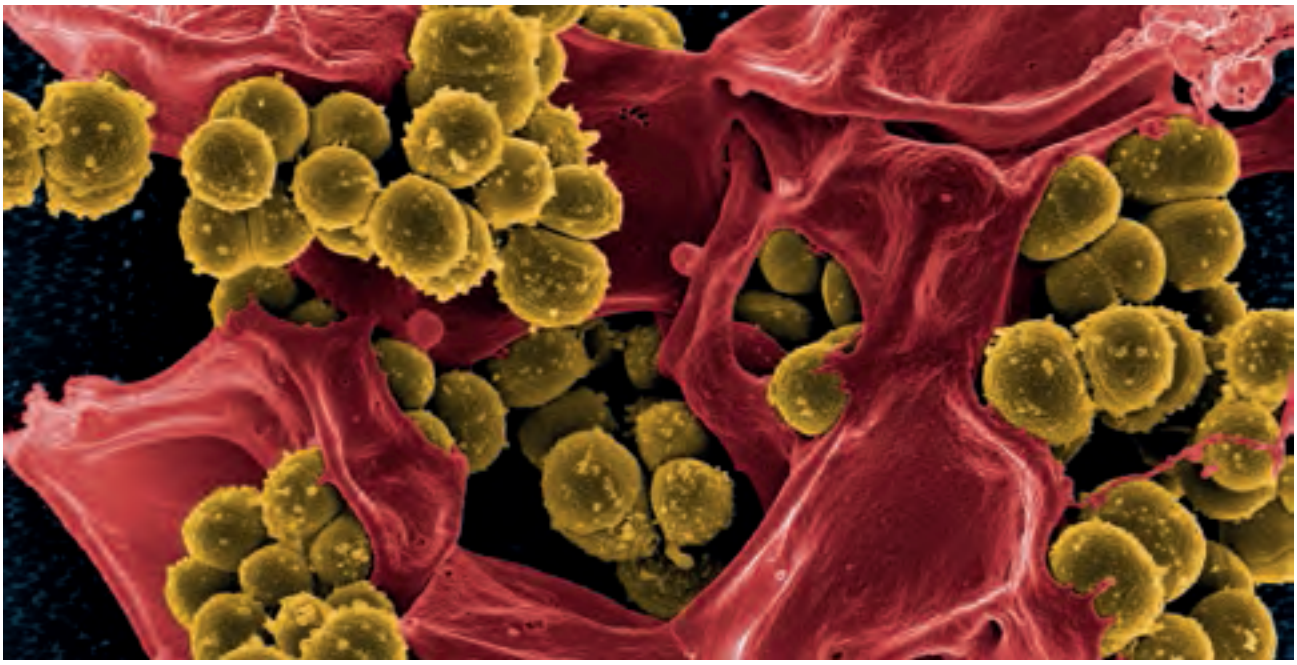
A personal highlight of the second day was a series of short talks all given by PhD students who were presenting some of these posters at the conference. For any starting PhD student it was definitely encouraging and inspiring to see my peers giving such articulate and interesting talks. One of these, given by Carla Brown from the University of Glasgow, described the use of naturally occurring colicins, antibacterial peptides produced by *Escherichia coli* under stressful conditions, as a potential new antibiotic treatment that may one day be administered in a probiotic supplement. Also in this session, Valerie O'Brien from the University of Washington gave a stellar talk on her work on vaccines for chronic urinary tract infections.

YMS 2014 was in short an inspirational meeting of minds from across the globe, where the big hitters of the future held their ground on the same bill as the big hitters of today. The meeting as a whole for an attendee was really enjoyable with opportunities to meet other PhD students from other universities as well as some of the leaders in the field – not to mention dancing with them at the ceilidh at the close of the meeting. As a starting PhD student I felt it gave me a valuable insight about the field and the research community in microbiology today besides being a real joy to attend.

John Allan
University of Dundee

John Allan has just started as a PhD student in the Division of Molecular Microbiology, College of Life Sciences at the University of Dundee under a BBSRC funded fellowship.

False-coloured scanning electron micrograph of meticillin-resistant *Staphylococcus aureus* (yellow) and a dead human neutrophil (red). NIAID



Best of the blog

As we come towards the end of yet another year, it's time to look back over a busy summer of science on the Society's blog *Microbe Post*. We've had some great stories over the past few months, no more so than our write-up of the emerging arbovirus, Chikungunya. Its name means '*that which bends up*' in the language of the Makonde people of Tanzania and Malawi, in reference to the severe joint and muscle pain that the virus can cause. Chikungunya has now been transmitted within the USA, making the disease of much interest to public health officials across the world (**http://microb.io/1lA2FZO**).

Also in the news a lot over the past few months has been the terrible Ebola outbreak affecting many countries in West Africa. Shortly after the outbreak began, we spoke to Dr Derek Gatherer from Lancaster University, who explained to us what the virus is and how it is spread to others (**http://microb.io/1pElz44**).

Earlier in the year, NESTA launched the Longitude Prize to much media fanfare. After a vote, the British public decided that the prize should focus on the rise of antibiotic resistance. Shortly after the announcement, Peter Cotgreave, the Society's Chief Executive, wrote about his thoughts on the prize and of an announced funding call from the Research Councils (**http://microb.io/1lhuipb**). Later in the summer, Joshua Ryan-Saha, Assistant Manager of the Longitude Prize, wrote a post for us giving some more details on what the prize hopes to achieve (**http://microb.io/LPrize14**).

In July I got to record what might be my most favourite interview. I went down to Kew Gardens to interview Dr Bryn Dentinger, one of the world's experts on porcini mushrooms. Bryn was working on a paper in which he reported discovering some new species of mushrooms in a packet of dried porcini he'd bought at a local shop (**http://microb.io/UsptmM**).

Continuing the food theme, Jon Fuhrmann investigated whether Panama disease – caused by the fungus *Fusarium oxysporum* – will cause the end of the banana, as we know it (**http://microb.io/1ks74xl**). Finally in this round-up, Jon spoke to Dr Adrián Pinto-Tomás from the University of Costa Rica to learn about how the pathogenic fungus *Escovopsis* might be used as a biocontrol method for leafcutter ants (**http://microb.io/1oJYdMP**).

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From bugs to drugs: pharmacy community open day extravaganza

David G. Allison & Graham J. Clarke

There is much public misconception and misunderstanding about the drug development process. In order to address some of these issues, the Manchester Pharmacy School hosted a family-orientated Community Open Day one wet Saturday in May.

Set against a public health theme, visitors were invited to journey through the stages of the drug development process to find a cure for a new and highly infectious (and of course fictitious!) micro-organism (*Bacillus zombieitis*) that turns human beings into zombies if infected. The organism 'spread' through contact with infected surfaces and by inhalation, and was extremely resistant to traditional antibiotics. The overall aim therefore was to identify the cause of zombieitis and to identify, develop, optimise, test, trial and market a new, effective antibiotic.

The activities

There was a strong microbiological theme to the event. The acquisition of micro-organisms by walking the mat of death (excellent use of fluorescent gel on a yoga mat) was used to explain the difference between resident, beneficial bacteria and transient, possibly harmful micro-organisms and the importance of good hygiene practice. There was opportunity to look down light microscopes at micro-organisms, including *Staphylococcus aureus*, *Escherichia coli* and *B. zombieitis*. A game of skittles was used to represent antibiotic resistance, with each skittle being a different bacterial species and the ball an antibiotic. Those that were knocked down when a ball (antibiotic) was rolled were susceptible while those that remained standing were resistant. Discretely placed velcro helped *B. zombieitis* (and also MRSA) remain resistant! Taking a ball from the participant represented stopping the course of antibiotics too soon. Photographs of antibiotic disc diffusion plates were on display to illustrate how preliminary antimicrobial properties might be assessed. Comparisons in activity for a range of antibiotics, including the 'new' product were shown against different bacteria, including *B. zombieitis*.

University staff and students and senior staff from Gilead Sciences were present to assist with activities and answer queries. Information about higher education and pharmacy as a career was available, as well as a Pharmacy Art Corner for all budding artists wishing to exhibit their interpretations of the drug development process. Prizes, including the book *The Secret World of Microbes* (kindly donated by the Society) were available for the best artwork and successful completion of a super quiz.

Success or not?

Feedback from completed questionnaires was overwhelmingly

Staff assisting with activities. Andrew McBain

positive, giving the whole event an average Likert scale rating of 3.7 out of a possible 4, with 98% stating '*I liked it a lot*' (74%) or '*I liked it*' (24%). Respondents said the event was '*fun*', '*interesting*', '*educational*' and '*inspiring*'.

Contributions of artwork and theatre from local and neighbouring communities and schools helped to make this an event by the community, for the community. On the basis of feedback questionnaire returns, approximately two-thirds of visitors had not previously been associated with the University of Manchester.

Final thoughts

Overall, the Open Day was deemed an overwhelming success, not only in terms of visitors leaving with an enlightened and positive view of pharmaceutical research but also in terms of community engagement. We hope that we have introduced pharmacy, research and indeed the benefits of higher education to a much wider audience than through conventional literature-based approaches. Moreover, events such as this have the potential to raise aspirations by de-mystifying academia.

Acknowledgements

Thanks to the Wellcome Trust for financial support [097820/Z/11/B] and the Society for General Microbiology for donating prizes, to Mother Hen for role-play activity, Ms J. Sarwar and selected Year 9 pupils from Chorlton High School for zombie actors and to the staff and students at Manchester Pharmacy School that contributed to the event.

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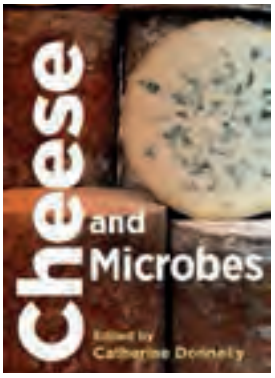
Reviews

Cheese and Microbes

Edited by Catherine W. Donnelly
Published by the American Society for Microbiology Press (2014)
US$125.00 ISBN 978-1555815868



Recent years have seen something of a counter-revolution both in brewing and cheesemaking and a massive resurgence in interest in artisan or craft products. This book, published by the American Society for Microbiology and edited by a director of the Vermont Institute for Artisan Cheese, looks at the complex microbiology of the huge range of cheeses produced around the world and has enlisted a panel of authors from the United States and (predominantly) Europe to do this.

An introductory historical chapter from the Editor is followed by an excellent short account of the basic features of cheesemaking, describing how in broad terms the process influences the microflora and consequently the product. The complexity of the underlying microbiology and biochemistry is such that starting from milk, a fairly uniform raw material, it is possible by slight changes in process conditions to produce a huge array of different products. This is well illustrated by the subsequent chapter describing the difficulties in devising simple systems of cheese classification. Chapters on mesophilic and thermophilic starters and mould-ripened cheeses are then followed by a series of contributions on neglected areas, which make this book unique. There are chapters on traditional mountain cheeses, Protected Designation of Origin Italian cheeses, traditional Greek cheeses, the biodiversity in yeast/bacterial consortia associated with surface-ripened cheeses such as Limburger, as well as an interesting contribution on the role of wooden tools as reservoirs of microbes in cheesemaking practice.

A penultimate chapter on issues of microbiological quality and safety is followed by a closing contribution from the Center for Systems Biology at Harvard on an ecosystem approach to studying cheese microbiology integrating the massive datasets available through high-throughput sequencing with measurements of ecosystem properties. This is an excellent book that doesn't lack hard science and might also give you an appetite.

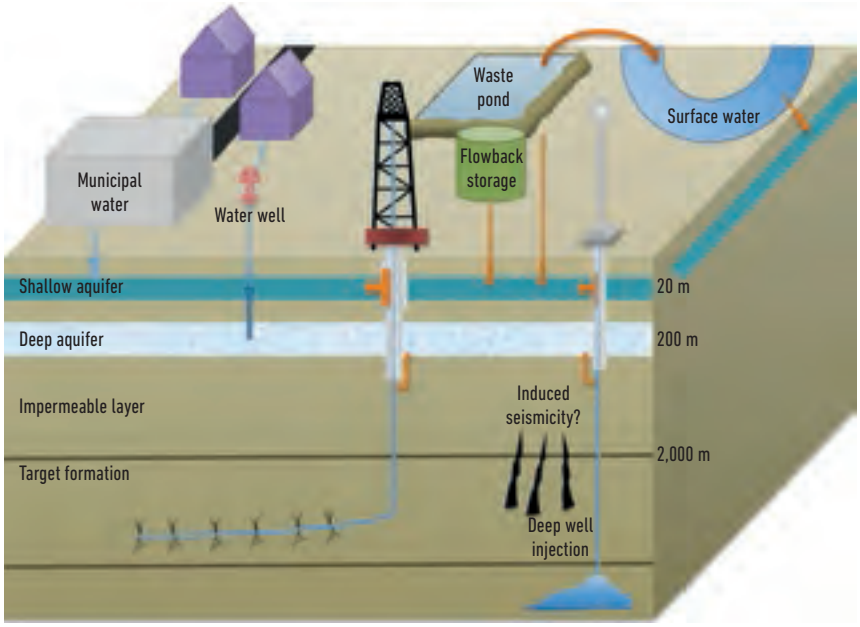
Martin Adams
University of Surrey

Comment

Hydraulic fracturing: what do microbes have to do with it?

Lee F. Stanish

Hydraulic fracturing, or fracking, is a hot topic. The process injects high-pressure fluid horizontally into deep wells to fracture impermeable rocks releasing pockets of trapped oil and gas. It has transformed the USA natural gas industry, with shale skyrocketing from 4% of total natural gas production in 2005 to 23% in 2010. With abundant shale gas reserves all over the globe, it is no surprise that other countries are eager to frack on their own soil.



The footprint of hydraulic fracturing on the landscape. The blue arrows show points of groundwater extraction. The orange arrows indicate the potential modes of groundwater contamination, and highlight areas in which to focus research efforts. Lee Stanish

The USA has served as a global test bed for hydraulic fracturing. In Pennsylvania, for example, over 6,000 unconventional natural gas wells have tapped into the underlying Marcellus Shale. Large-scale fracking now spreads across the country to states such as Utah, Wyoming and California. The dizzying pace of development has raised public concerns that the risks and impacts to water quality beyond obvious accidents and spills are not well known. To compound the problem, natural gas development is occurring close to people's homes, sometimes literally in their backyards.

Microbes play a critical role in groundwater quality; pollutants can alter the composition of groundwater microbial communities. In fact, their sensitivity to pollutants may allow them to be useful for monitoring contamination from fracking activities. Currently, little is known about the risks to groundwater from fracking, and even less about the effects on groundwater microbiota. This is due at least in part to a lack of baseline data for comparison, meaning that great research opportunities exist to learn about the microbes that live in the subsurface and how they respond to fracking contamination.

Two important avenues exist for fracking to contaminate groundwater. The first involves the fluids used for and produced by hydraulic fracturing. The most likely mode of contamination arises from spills and leakages on the surface while the well is fracked or during transport and storage, which primarily affect surface and shallow groundwater. Fluids could also enter groundwater through faulty well casings. There are three chemically and biologically distinct types of fluids: fracking fluid, flowback and produced water.

Fracking fluid is injected into the well under high pressure to fracture

rock so that the oil and/or gas can be extracted. Of the hundreds of known chemicals used for fracking, many are added to control microbial growth, and include biocides (e.g. glutaraldehyde), acids and oxygen scavengers. In the USA, the requirements for disclosing the chemicals used for fracking vary by state, and public disclosure is sometimes voluntary. Moreover, companies are not required to disclose the composition of proprietary chemicals, so-called 'trade secrets'. Complete public disclosure of these chemicals would allow us to study their effects. A useful (albeit incomplete) database of the chemicals used in USA fracking operations is available at **FracFocus.org**

After fracking occurs, the higher pressure within the well forces some of the fracking fluid out, and this is referred to as flowback. Flowback typically is generated for a few weeks after fracking. This wastewater contains high levels of dissolved solids, salts and fracking chemicals, and must be stored and treated or reused. Up to 70% of the injected fluid is not recovered, and its fate in the subsurface is unclear. When the flowback runs out, fluid that exists within the oil or gas-producing formation, called produced (or formation) waters, can be recovered. These fluids are very salty and can contain harmful levels of metals and radioactivity.

We are beginning to understand the succession of microbiota in the fluids used for and produced from fracking. Despite best efforts to prevent growth, microbes survive in fracking fluids and likely take advantage of the energy sources added to fracking fluid. Fracking fluid selects for taxa that can survive the biocide, and the survivors can grow on the ample nutrients in the fracking additives. Salinity becomes an important driver of community-level changes as energy sources run out and formation waters mix with the fracking fluid. Salt-tolerant, fermenting organisms such as *Halolactibacillus* dominate in the initial flowback and may continue to consume the organic carbon sources within the fracking fluids. Flowback is sometimes used again to frack other wells, and likely enriches for salt-tolerant, biocide-resistant organisms. Once oxygen and energy sources are depleted, anaerobic and salt-tolerant members of the *Firmicutes* such as *Halanaerobium* comprise the vast majority of the microbiota found in produced water. At this stage, it is thought that the microbiota originate from the target formation. The composition and succession of these microbiota may allow us to trace the timing and sources of groundwater contamination from fluids produced during hydraulic fracturing.

The second mode of contamination comes from stray gas migration. Numerous recent studies suggest that natural gas migrated into groundwater as a result of fracking activity. These studies found thermogenic methane in the groundwater, or methane that originated from the target formation. This methane is generated abiotically under high temperatures and pressures. While finding thermogenic methane in groundwater clearly connects deeper subsurface processes with the shallow subsurface, some groundwater systems are 'leaky' and can contain thermogenic methane naturally. Without a doubt, the provenance of methane only provides part of the story, and reinforces the need for multiple lines of evidence.

Microbes may provide another line of evidence, and I am currently working to evaluate the potential for microbiota to predict groundwater geochemistry. During the summer of 2013, a sampling campaign was conducted to characterise the microbiology of groundwater in the Denver-Julesberg Basin of Colorado, which has undergone rapid shale gas development. A large research programme recently established to quantify the environmental, economic, and societal impacts of fracking in the Rocky Mountain region is already yielding promising results. I collaborated with their research team to characterise the microbiology of groundwater from private wells in close proximity to fracking activity and relate it to geochemical data. Even from this relatively small study, we have gleaned valuable insights about the microbiota, including differences between shallow and deep groundwater and possible indicators of *in situ* methane production. The next step is conducting targeted experiments in order to establish links between fracking activity and groundwater microbiology.

The microbiology of groundwater is clearly complex, and our knowledge of how extraction activity influences the microbiota is still in its infancy. Still, there is real potential in using microbes to monitor fracking contamination. With continued research, appropriate regulations, and careful monitoring, we can ensure the responsible development of this vast energy resource.

Lee Stanish

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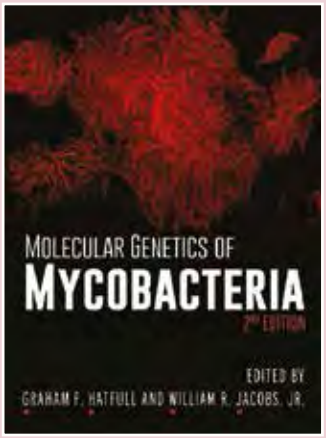
Further reading

Information on the Rocky Mountain project can be found at **AirWaterGas.org**

An updated list of scientific articles and other resources related to fracking are on Lee's blog, **http://yourweeklymicrobe.blogspot.com**

New from the American Society for Microbiology Press



September 2014
824 pages
Hardback
978-1-5558-1883-8
£110.00

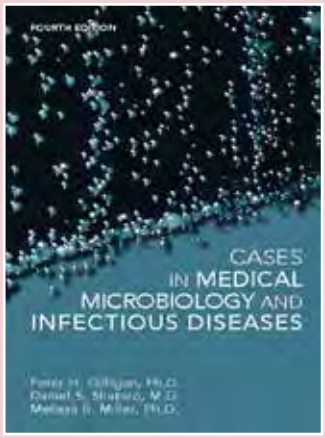
Molecular Genetics of Mycobacteria, Second Edition

Graham F. Hatfull, University of Pittsburgh, USA, and **William R. Jacobs, Jr.,** Howard Hughes Medical Institute, USA

This book is an invaluable resource for anyone interested in the molecular genetics and molecular biology of mycobacteria.
Mycobacterium tuberculosis causes one in four avoidable deaths in the developing world and kills more adults than malaria, AIDS, and all tropical diseases combined. Tuberculosis was named a global health emergency by the World Health Organization, a distinction no other disease has received. Although the study of mycobacterial genetics has expanded dramatically, with new investigations into mycobacterial growth, replication, metabolism, physiology, drug susceptibility, and virulence, most of the problems in tuberculosis control that existed in 2000 remain today.

Key Features

- Discusses key areas of current research in mycobacterial genetics
- Explains the genetics of the physiology, metabolism, and drug sensitivities of M. tuberculosis
- Presents genetic approaches for manipulating M. tuberculosis



September 2014
604 pages
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Cases in Medical Microbiology and Infectious Diseases, Fourth Edition

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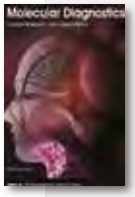

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