MICROBIOLOGY TODAY

48:1 May 2021

Life on a Changing Planet

Exploring the relationship between climate change and the microbial world

MICROBIOLOGY SOCIETY

Editorial

Welcome to the May 2021 issue of *Microbiology Today*! This is my first issue as Editor, and I feel that I have some very big shoes to fill following on from Rowena Jenkins and her four-year tenure in this role. Thank you, Rowena, for bringing together some excellent articles and for all your support during the handover of the editorship. I also want to say a very big thank you to Ellen Hinkley and Ruth Paget for helping me settle into this new role, and to the authors contributing to this issue in the backdrop of COVID-19 restrictions and all the disruption associated with it.

The title of this issue is 'Life on a Changing Planet'. Although, as humans, we have all experienced significant and acute change across the planet as a consequence of the COVID-19 pandemic, this is not the sole focus of the May issue. We instead look at the chronic change that we have inflicted on Earth and the impact this has had on the microbial world. This issue starts with Sandra Pearson exploring the rise of Lyme disease in the UK. This vector-borne infection has increased in incidence to several thousand cases a year since it was first encountered in the 1980s. Sandra describes the possible role of climate and biodiversity changes, and our direct interaction with nature as reasons for this increase.

Next, we turn our attention to fungi. Whilst fungi are adapting to climate change, Marta Filipa Simões warns us in her article that these adaptations can be to the detriment of humans. Marta shows us how changes in climate have allowed new human pathogens to emerge and how a variety of phytopathogens are now able to spread to new environments and cause damage to crops, either directly or indirectly, as a consequence of mycotoxin contamination.

An increasing human population means an increasing requirement for food. One area which has seen significant growth to match this requirement is aquaculture. Unfortunately, as in agriculture, microbial pests represent a problem for aquaculture. A large proportion of 'pests' in aquaculture are protists, and to review the threat posed by these organisms we have an article written by members of Protistology-UK, which in 2018 became a partner organisation to the Microbiology Society.

The next two articles each explore an ecosystem impacted by climate change. Arwyn Edwards, Jarishma Gokul and Sara Rassner are up first with their article microbes in icy ecosystems. They describe an incredible diversity of microbial life trapped within and below ice waiting to be explored in detail. Unfortunately, it seems that some of this life is contributing to the demise of these ecosystems, as the authors go on to describe the action of algae and their photosynthetic pigments absorbing thermal radiation and hastening glacial melting.

Moving away from the poles of the planet, Christian Voolstra writes about the microbiology of coral resilience. The warming of Earth's oceans has been disastrous to the ecosystem of the coral holobiont, with disruption of this ecosystem leading to the coral bleaching and death we have seen reported in the media. In spite of this, Christian describes the promise of introducing thermotolerant micro-organisms into coral ecosystems as a way of protecting the coral we have left.

Can micro-organisms save us from our climate catastrophe? This is the question posed by André Antunes in our last article. Various micro-organisms have the capacity to utilise existing greenhouse gasses or restrict their production. André explores how this capacity can be exploited with examples such as microbial CO_2 capture for the creation of calcite or the use of probiotics to reduce methanogenesis in ruminants.

We finish this issue with a highly topical Comment piece. Rosa von Borries and Rachel Lowe warn us of the danger of wildfires and how the pollution they generate can synergise with the symptoms of COVID-19 to cause increased severity and mortality in at-risk groups. Given the increase in the length and severity of wildfire seasons in recent years, Rosa and Rachel discuss the need for further research to investigate the interplay between wildfire pollution and respiratory infections in order to identify strategies to protect vulnerable individuals.

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Contents

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From the President

The Microbiology Society has now held its first online Annual Conference, the second in a series of online meetings that will take place in 2021, following on from *Candida* and Candidiasis at the end of March. In light of last year's difficult but inevitable decision to cancel Annual Conference in Edinburgh, it was even more exilarating to virtually 'meet' so many of you at Annual Conference Online 2021 and reassuring that you are all still out there!

The week provided a chance to delve into some of the outstanding and diverse research that has been carried out in the last year, in spite of the many obstacles faced, and demonstrated the resilience and determination of the microbiology community. To run our programme of events and keep our community engaged and in touch has required our office staff to be resourceful, imaginative and agile, working long hours, remotely, to test different platforms and then make them work. As a society, we have learned a great deal about new ways of running events and hope these will carry forward to even better, more inclusive meetings in the future. I am personally both impressed and grateful for their professionalism and dedication to keeping the Society not just running, but running well. I look forward to seeing many of you at our other events, which must of course continue online due to the unpredictable nature of the pandemic. This will include the Microbiology Society Roadshow events for those based in Norwich this month, and elsewhere in the UK later this year. Our Focused Meeting programme will also continue online this year, with themes covering avian diseases, anaerobic microbes and yeasts – find out more on pages 38–39.

Those of you that attended Annual Conference, may already have attended the webinar in which we outlined plans for our project to transform *Access Microbiology* into an open peer review platform. This platform will allow authors to post their manuscripts as preprints online immediately and receive AI review reports on their manuscripts, opening up the peer review process. Read more about the new platform in our blog series (**microb.io/blog**).

Another highlight of this year's Conference, and an unexpected benefit of having missed out last year, is that we had a grand total of nine Prize Lectures awarded to scientists in 2020 and 2021 who have each made significant contributions to microbiology. We are currently welcoming nominations for the Microbiology Outreach Prize, the 2022 Prize Lectures and the 2023 Prize Medal – submit yours on our website (**microbiologysociety.org/PrizeLectures**). Please remember, this is your society and if you think someone deserves recognition, don't leave it to someone else to nominate.

We have also just launched our Unlocking Potential Grant Fund, a fundraising call to allow us to open an important new grant stream to unlock and harness the potential of members. We will use donations to make funds available, via our 'Unlocking Potential' grant, to those who may require an extra level of support to help them progress or deal with a situation that may hold them back from achieving what they could. It is only with your help that we will be able to provide this level of bespoke support. In doing so, we will help not only to sustain microbiology but develop future leaders, who might, in turn, one day provide solutions to global challenges.

Times have been tough over the last year, but there is hope in science; in the vaccines, the testing and the research that have all been fundamental in increasing our understanding of SARS-CoV-2 and to start tackling the disease. I am proud to be part of a community in which so many have contributed to all parts of the solution to this global crisis. Climate change, another global crisis with ramifications for life across the planet, is the focus of this issue, which demonstrates how key microbiology is and will continue to be in helping to help steer the way forward.

Judith Armitage
President

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From the Chief Executive

The COVID-19 pandemic is still a long way from over. Millions of people around the world still have the disease and many more will die. More still will suffer the longer-term effects of what has become known as long COVID. But we can see light at the end of the tunnel. The world has a number of safe and effective vaccines. For those who fall ill, we have better treatments. Preventative measures such as ventilation and social distancing are better understood and accepted. It is possible to imagine a world in which, although the SARS-CoV-2 virus has not gone away, it will no longer dominate our lives in the way it has for over a year.

To get us to this point, the overall response to the pandemic has been multifaceted. Economic and social measures, mental health support, logistical challenges and a great deal of common sense and neighbourliness. And at the heart of these responses has been the science. The many, many roles that microbiologists have played have shown more than ever how important our field is, and members of the Microbiology Society have been at the forefront of this vital work.

Some of these responses have been very obvious and direct frontline fighting of the virus. From the outset, the Society tried to help the UK's testing laboratories, for example. We did not agree with every decision that was taken and we had many discussions with the people whose job was to develop and implement the testing strategy. But in the circumstances, there was no time to debate the perfect model. So, we helped identify qualified people who could ensure that the testing would go ahead as quickly and effectively as it possibly could and dozens of you responded.

Members of the Microbiology Society have also been involved in advising governments, both in the UK and in other countries. Some of this has been high profile and public, where members are on formal advisory bodies, but a lot of it has been behind the scenes. On one occasion, we took a phone call asking if we could identify experts in five different areas and get them on the phone to a senior government figure within the next two hours. We did it.

Perhaps most obviously, members of the Society have been at the forefront of keeping the public properly up to date about what we know and what we don't know about the virus and its consequences. A big change in the last two decades has been the media's insatiable appetite for a range of expert voices who can speak directly to the public, answering their questions clearly and authoritatively, listening to their concerns, addressing them where we know the answers and being honest when we don't.

And of course, behind all of this is the research that generates this knowledge. The Microbiology Society's SARS-CoV-2 workshop brought together people working on the virus, many of them new to coronaviruses and some of them new to virology. As well as forging links and sharing knowledge, it gave researchers access to one another's resources and expertise to advance the field. Much of that work has been published in our journals, including work on the human body's immune response to coronaviruses, interesting case studies of individual patients, genetics of how the virus suppresses host genes, assessments of detection techniques and a study of the model of acute respiratory infection.

On the Society's website, there is a hub that brings together the rich and varied contributions and responses that members of the Microbiology Society have made to this pandemic, the biggest global experience shared by billions of people around the world for many decades (**microb.io/3m8FOM7**).

Such a collection of material can never be complete and if there are contributions that you would like to see included, let us know. But it can give a sense of the vast, wide and deep contribution that our community has made to fight the pandemic, of which you, the members of the Society, can be extremely proud.

Peter Cotgreave
Chief Executive

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News

Professor Tony Trinci

Mrs Margaret Trinci has asked us to post a sincere thank you message for the many caring thoughts and condolence messages her family received from members of the Society following the death of former Society President Professor Tony Trinci in October last year.

Meet the President and network online with fellow microbiologists in Norwich

The Microbiology Society Roadshows are continuing online in 2021, supporting microbiologists in local areas to connect and share knowledge.

The next Microbiology Society Online Roadshow will be held on **25 May**, for microbiologists based in Norwich. Find out more on our website (**microbiologysociety.org/Roadshow**).

Microbiology Outreach Prize and Prize Lecture nominations

Nominations for the Microbiology Outreach Prize, the 2022 Prize Lectures and the 2023 Prize Medal are now open. Nominations are welcome from any member of the Microbiology Society, regardless of membership period or category, by **27 May 2021**. Submit your nomination online (**microb.io/2zEwBHf**).

News

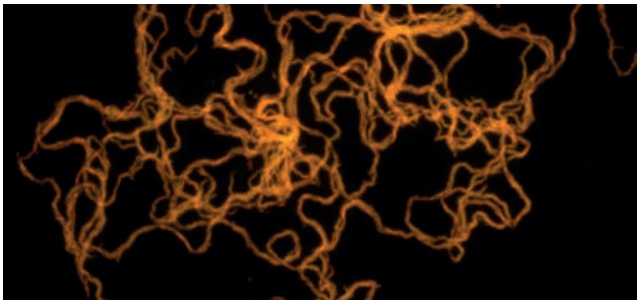
Claudio Ventrella/iStock

Microbiology collections

In 2022, *Microbiology*, the founding and flagship journal from the Microbiology Society, will be celebrating 75 years since publishing its first issue. In the run up to its anniversary year, the journal is launching a series of themed collections that celebrate the breadth of microbiology and showcase why microbiology matters. You can find details of the first two collections below.

Mycobacteria

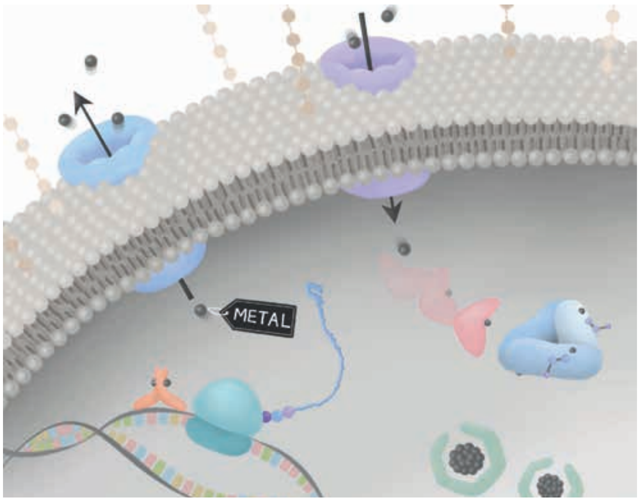
Guest-edited by Dr Riccardo Manganelli, this collection will highlight all aspects of mycobacterial biology, with a particular focus on physiological aspects, such as stress response mechanisms, regulatory networks and metabolic pathways, that might lead to a better understanding of the intriguing aspects of mycobacterial host–pathogen interaction and the design of new strategies to fight these important pathogens. Find out more and read the articles currently in the collection online (**microbiologyresearch.org/content/mycobacteria**).



Marta Peracchi

Metals in Microbiology

Guest-edited by Dr Jennifer Cavet and Dr Karrera Djoko, this collection of keynote research articles will highlight research on metal–microbe interactions, bringing together advances in our understanding of how microbes handle metals, the utilization of metals in proteins and the importance of metal-handling systems in host–pathogen interactions. It will also include research that exploits these systems in industrial processes, the development of metal-related antimicrobials and in metal bioremediation and biorecovery.



Jin Hong

Find out more and read the articles currently in the collection online (**microbiologyresearch.org/content/metals-in-microbiology**).

Keep an eye on **microbiologyresearch.org** and our social media platforms to make sure you don't miss upcoming collections. Authors wishing to submit to the collections should do so via the online submission system (**editorialmanager.com/mic**) and note in their cover letter which collection their submission is intended for.

The Microbiology Society is a not-for-profit publisher and we support and invest in the microbiology community. All journals income is invested back into the Society, be it through funding grants, scientific meetings or helping to fund our policy activities.

New Microbiology Society open research platform to launch in October 2021

In October, we will be launching a new open research platform. The project, funded by a Wellcome Trust and Howard Hughes Medical Institute grant, will involve converting our sound science journal, *Access Microbiology*. Find out more: **microb.io/3ddZGui**.

News

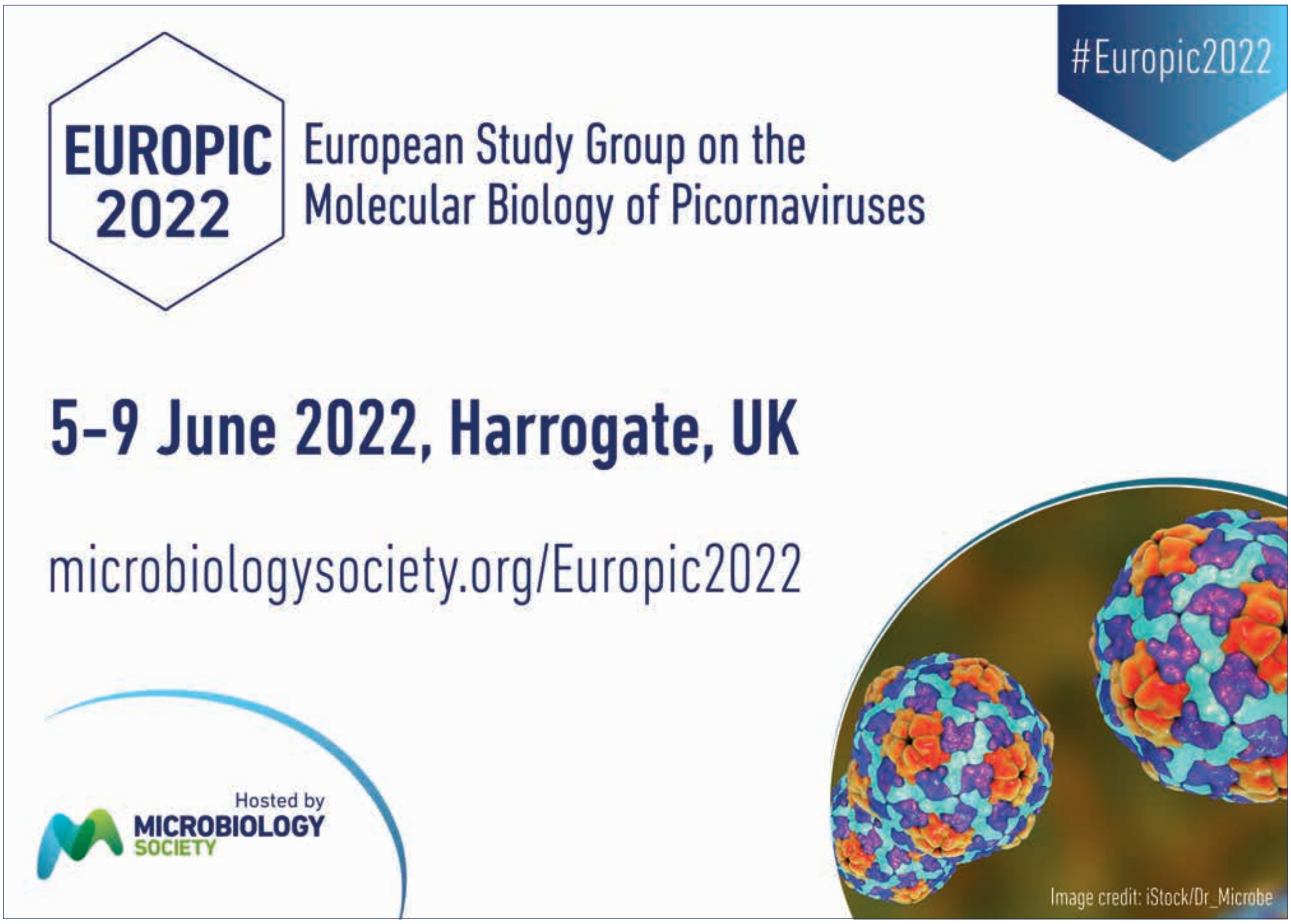
Grant deadlines

Date	Grant
1 June 2021	Travel Grant – for eligible members wishing to present at conferences or attend training events taking place between 1 July and 30 September 2021. Events can be taking place in-person or virtually.
1 September 2021	Travel Grant – for eligible members wishing to present at conferences or attend training events taking place between 1 October and 31 December 2021. Events can be taking place in-person or virtually.
30 September 2021	ECM Forum Event Fund – for ECM members requiring sponsorship for local events (in-person or virtual).
3 October 2021	Education and Outreach Grants – for eligible members requiring support for projects to communicate or teach microbiology.
	International Development Fund – for eligible members wishing to contribute to the development of microbiology in low- and lower-middle-income countries.
	Research Visit Grants – for eligible members wishing to make a research visit to a collaborator.

For more information please visit the website (**microbiologysociety.org/grants**).

Connect with the Microbiology Society on social media:

@MicrobioSoc **@microbiosoc**



Nicolas Locker: Reviews Editor for *Journal of General Virology*

Nicolas Locker is a Professor of Virology at the University of Surrey and Reviews Editor for the *Journal of General Virology* (JGV). His interests involve understanding how our cells respond, recover and adapt to stress, using several virus models. This adaptation is important to the virus–host interface and central in antiviral responses. His lab wants to uncover novel fundamental cell biology mechanisms and novel leads for antiviral therapies.

Nicolas Locker

When did you first decide you wanted to do science (and why)?

I did not grow up with a passion for science, but really liked to do stuff with my hands and experiment, like cooking! As such I was taken by studying chemistry and biochemistry in my hometown (Orléans, France). That interest morphed into a PhD in structural biology as being able to visualise how complex things looked fascinated me. Understanding how these molecular machines work was the next step, with viral proteins or RNAs proving a vast playing field. These days we focus on how viruses hijack or retune proteins central to the control of gene expression and stress responses.

What is your biggest professional achievement?

The three-and-a-half-year journey with one of my early PhD students that saw the laboratory move into the stress responses field, seeing a new line of research take over our other interests, making new collaborations worldwide and working with a great student now back as a laboratory PI in his home country, Iraq.

What would you be doing in your career if you weren't a scientist?

I'd probably live on the coast somewhere to combine my passion of water sports with a job in the food industry.

When did you join the Society and why did you join?

I joined the Society a couple of years after establishing my laboratory at Surrey in 2009; the range of Society events, from the smaller Focused Meetings to the Annual Conference grand show, was pretty much the best way of getting to know people in the UK and to create my own professional network. These early connections have led to collaborations still going strong a decade later.

Please describe your role on the Editorial Board.

I am the Reviews Editor. Reviews are an important part of the JGV ecosystem and complement the range of articles published. Good reviews are hard to come by but are so fundamental to what we do; they help us understand novel fields into which we are thinking of going, provide a 'state of the union' summary informing what we plan in daily experiments, and they also offer a window into the future: the questions remaining to be asked; hypotheses to be tested; I love reviews! My role is to help identify these topics and those most suited to tackle them, and making sure they get written!

What motivated you to become part of the Board?

I have published in JGV before; I love the ethos of the Editorial Board, creating a closed loop where the journal serves the community and the community feds back into it. It's at the core of what we do at JGV.

Why are Society journals important?

Would the Society be there without journals? Would all those wonderful events happen? Travel grants or internships? This is why we need Society journals and I think it is our responsibility to publish in Society journals that benefit our community.

What do you think the future holds for microbiology?

If the last 12 months have told us anything it's that one should answer this carefully! From one pandemic to the next, we have to be better at understanding and predicting how pathogens can jump the species barrier. But one thing that will persist and develop in the future is how much more open and collaborative science has been. The pace at which data are published in the open space, new collaborations set up on a Twitter feed; it's making us better at doing real collaborative science.

UNLOCKING POTENTIAL FUND

The Society is fundraising for a new grant, to help members progress in their careers and to reach their full potential.

We know from feedback from our members that some face barriers to career progression. Everyone faces a career challenge at some stage – even knowing which career step to take next can be difficult to navigate. We may suffer from imposter syndrome or lack confidence. We may face a deep-rooted and fundamental problem like discrimination; we may need support to overcome a change in circumstances or we may just need someone to point us in the right direction.

That's why the Microbiology Society is introducing a new grant, a grant designed to help members help each other to rise to the specific challenges they may currently be facing. The Unlocking Potential Grant will support members by providing one to one bespoke support. It may be in the form of a careers coach, resilience expert or mentor or it may be a career development package. Whatever form it takes, it will be tailored to the grant recipient and unique to their needs.

> "I received a small grant early in my career, and without it, I really doubt I would be where I am today. For just a few hundred pounds, my career was changed. Somebody's career can be changed by just giving a few hundred pounds and that's where this grant comes in."
>
> *Professor Judith Armitage*
> *President of the Microbiology Society*

Specialists will work with the successful grant applicant to address the issues of concern, enabling the member to help them fulfill their potential.

To do this we need your help. We are fundraising to allow us to open this important new grant stream. It is only with your support that we will be able to provide this level of bespoke support. In doing so, we will help sustain microbiology and develop the leaders of the future, who might in turn one day provide solutions to global challenges from urgent problems demanding immediate solutions such as new and emerging diseases, through to long-term issues like antimicrobial drug resistance, food security and environmental sustainability.

If you would like to find out more about the fund, visit **microbiologysociety.org/UnlockingPotentialFund** or contact Andrew Zsigmond, Fundraising Manager, at **unlockingpotential@microbiologysociety.org** or call 07990 823696.

Lyme disease in the UK: the continued rise of an emerging zoonotic infection

Sandra Pearson

Lyme disease or Lyme borreliosis is a vector-borne zoonotic infection transmitted to humans by the bite of an infected tick. Ticks from the genus *Ixodes* act as the vector, and the disease is caused by the bacterium *Borrelia burgdorferi*. It is now the most common tick-borne disease in the northern hemisphere. In the UK, the recorded incidence has been steadily increasing since the first confirmed case was reported in 1986. This reflects a genuine increase, although greater awareness and increased testing are relevant. The reasons for this continued emergence are complex, possibly including climate change, changes in land management and biodiversity, and human interaction with nature.

It is important to understand key contextual factors in order to consider possible drivers. These include the unique nature of the bacterium; the central role of the tick vector; and the complex and intricate dynamics involved in the ecology of *Borrelia* and ticks, and their animal hosts.

Epidemiology

In the UK, epidemiological data refers only to laboratory-confirmed cases, which underestimates the true incidence. In England and Wales, there were 2.7 recorded cases per 100,000 population in 2017 (1,579 cases), with an estimated 2,000–3,000 likely additional cases. Whilst Lyme disease is not common in the UK it is no longer rare, with incidence rates highest in Scotland and southern counties of England. Lyme disease is more common in mainland Europe, particularly Central/Eastern Europe, and the north-eastern USA. Across Europe, data collection methods and surveillance criteria vary, so direct comparisons are difficult. A 2014 review of Western European data found a mean population-weighted incidence of 22/100,000 person-years, with substantial variation between countries. Highly endemic countries such as Slovenia, Germany and Austria, the Baltic coastline of southern Sweden, and some Estonian and Finnish islands may record over 100 cases per 100,000 population per year. In 2018, the average recorded incidence for the north-eastern USA ranged from 2.3/100,000 in Massachusetts to 92/100,000 in Maine.

Clinical picture

Following the bite of an infected tick, early localised Lyme disease begins in the skin with a slowly expanding rash called erythema migrans in about 60% of cases. There may be fatigue, headache, malaise and flu-like symptoms. Treatment with antibiotics in the first few weeks and months is vital since early treatment is more effective. If a diagnosis is delayed, late Lyme disease can cause a multi-systemic illness that may involve the nervous system, joints, heart, skin and eyes. Post-treatment, Lyme disease may result in a range of debilitating symptoms, with 12–50% of patients reporting persistent symptoms and significant impairment in quality of life. Interestingly, symptoms may resemble those seen in long COVID, and further research is needed into the cause and treatment.

Borrelia burgdorferi

There are many genospecies of *Borrelia*, and those which cause Lyme disease belong to the *Borrelia burgdorferi* sensu lato complex. Three main genospecies are involved, and symptoms may vary accordingly:

- *Borrelia burgdorferi* sensu stricto: causes Lyme arthritis, especially of large joints such as the knee. The main cause of Lyme disease in North America.
- *Borrelia garinii*: associated with neurological symptoms.
- *Borrelia afzelii*: associated with skin and atypical neurological presentations, more common on mainland Europe.

Ixodes ricinus tick on a leaf. Erik Karits/iStock

- Other pathogenic genospecies include, but are not limited to: *Borrelia spielmanii*, *B. bavariensis* and *B. bisettii*.

Borrelia miyamotoi, discovered in Russia in 2011, is endemic in Europe and the north-eastern USA. It has been identified in UK ticks, with no recorded human cases to date. It causes a Lyme-like illness with symptoms similar to relapsing fever: high fevers, respiratory and gastro-intestinal symptoms but no rash.

The enzootic life cycle of ticks and *Borrelia*

Ticks are small blood-sucking arthropods that need humidity and shade to survive. They can be found in woods, fields, rough pasture and moorland but may thrive in urban parks and gardens. Ticks are more active from April to October but continue their quest for food during milder winters. The varying seasonal incidence of Lyme disease reflects increased tick activity during warmer months, peaking in June with a smaller peak in September.

There are four stages to a tick's life cycle: egg, larva, nymph and adult. Ticks feed on the blood of animals and ground-feeding birds and acquire *Borrelia* whilst feeding on the blood of an infected host. In the UK, in locations where studies have been carried out, 0–16% of ticks were shown to be infected. *B. burgdorferi* may be transmitted to the next stage during moulting, but not to the eggs. Survival of *Borrelia* is therefore not only dependent on the tick vector, but also the availability and abundance of wildlife hosts such as mice and ground-feeding birds which act as a natural zoonotic reservoir for the bacteria. Deer play a key role in dispersing ticks over large areas and supporting reproduction, but possess natural immunity to *Borrelia*, so do not carry the bacteria. In addition, migratory birds may spread ticks and tick-borne diseases over large distances.

B. burgdorferi has evolved as an obligate parasite, managing the difficult passage between tick and warm-blooded host via tightly regulated differential gene transcription, which controls the expression of a range of outer surface proteins necessary for key functions such as survival in the flat, unfed tick, and virulence and immune evasion in the animal host.

Ticks may host diverse microbial communities including pathogens such as *Anaplasma*, *Babesia*, *Rickettsia* and certain viruses. There is a risk of importing foreign tick species on pets and livestock from abroad, potentially introducing non-endemic ticks and newly emerging human and animal diseases.

Possible effects of climate change

Climate change may result in changes in temperature, rainfall, humidity, snow cover and vegetation. Studies from Europe show that ticks have spread into higher latitudes and altitudes. Tick surveillance from various countries shows they have become generally more abundant. Micro-climates such as south-facing slopes of mountains may favour tick survival. Evidence suggests that ticks can adapt to survive and thrive in colder, drier conditions. These changes are thought to be related to the effect of climate change, directly on ticks and indirectly on the abundance of their animal hosts, particularly the presence and spread of roe deer.

Changes in biodiversity and land management

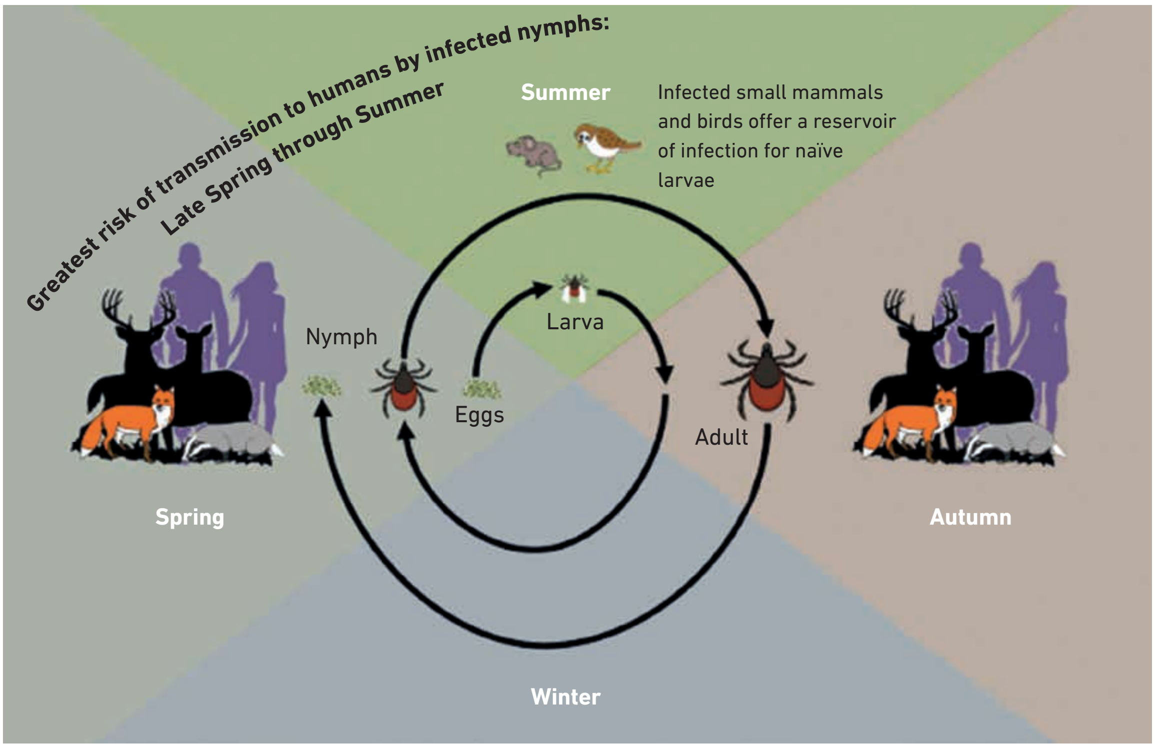
Since the main reservoir for *Borrelia* in nature is small mammals, such as mice, factors which alter their abundance can have a cascading effect on tick density, tick infection rate and risk of Lyme disease. Landscape change and the effect on reservoir host abundance is thought to be a key factor behind the rising incidence of Lyme disease. Green corridors which allow wildlife to move between different areas may favour the spread and increase of tick populations. Studies show that the density of tick populations may be increased in areas adjacent to woodland, particularly deciduous woodland. Any factor, whether man-made or natural, which leads to significant loss of larger predators at the top of the food chain may have a significant impact on the survival of animals upon which ticks feed and reproduce, and small mammals such as mice which form the main reservoir for *Borrelia* in nature.

Man's interaction with nature

There are wide-ranging health benefits from engagement with the natural world and outdoor pursuits which cannot be over-emphasised. Indeed, outdoor exercise has played an

The life cycle of *Ixodes* ticks and their relationship with reservoir and dead-end hosts.

Dr John Tulloch, Liverpool University, from his 2019 PhD thesis 'An appraisal of health datasets to enhance the surveillance of Lyme disease in the United Kingdom'



essential role in people's lives during the current COVID-19 pandemic. At the same time, both occupational and leisure activities may increase tick exposure and the risk of Lyme disease.

The way forward

Because of the enzootic life cycle of ticks and *Borrelia*, as described above, it follows that it is not possible to eradicate Lyme disease from its natural habitat. However, the public health risk of ticks and Lyme disease can be managed by the following interventions:

- Enhanced tick surveillance to monitor the environmental risk.
- Conservation practices: land, wildlife and forest management.
- Improved awareness and education about ticks and Lyme disease for policy-makers, healthcare professionals, veterinarians and the general public, by raising awareness without causing undue alarm.
- Tick bite prevention strategies.

Currently, there is no vaccine for Lyme disease licensed for use in humans, though some are in development.

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Sandra Pearson is a retired consultant psychiatrist and was medical director of the UK charity Lyme Disease Action until 2020. She co-authored the Royal College of General Practitioners (RCGP) eLearning module and the RCGP Spotlight Project on Lyme disease. She has lived experience of Lyme disease as a carer.

Lyme Disease Action (LDA) is a UK charity which aims to raise awareness of Lyme disease and lobbies for research and improved services. It provides accredited information for the public, patients and health professionals.

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How did you enter this field?

I became involved with Lyme Disease Action after my husband developed severe Lyme disease in 2008, which had a major impact on both our lives. My role as Medical Director enabled me to attend major microbiology conferences such as ECCMID, as well as key European and American tick-borne diseases conferences. I had the great privilege of meeting and speaking with leading researchers and academics in the field. Through reading and attending meetings and conferences, I became fascinated by the advances in science which were beginning to enable a better understanding of *Borrelia burgdorferi* and Lyme disease.

Why does microbiology matter?

I think it must be both a challenging and exciting time to be involved in microbiology. Advances in the fields of molecular microbiology and genomics are pushing back the frontiers of science, raising the possibility of new advanced tests, treatments and vaccines for a range of infections. I hope that our understanding of Lyme disease will benefit from such scientific advances, which is of vital importance for patients and clinicians who may be facing challenges in diagnosis and treatment.

Impact of climate change on fungi

Marta Filipa Simões

Climate change

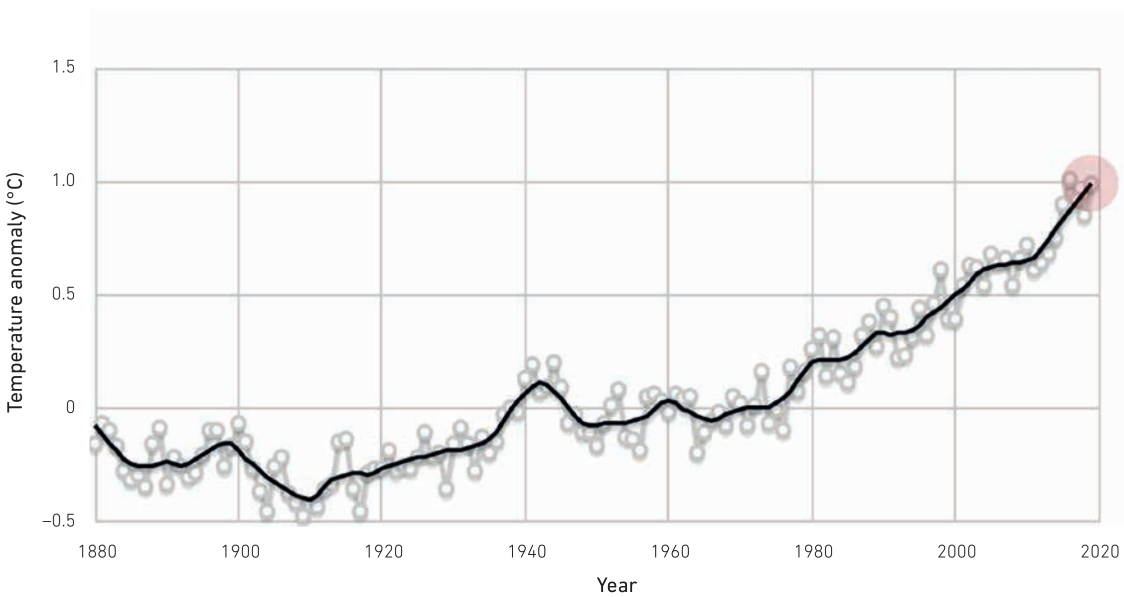
Earth's climate has gone through different changes and it is now unquestionable that it is warming at an increasing rate. These adverse changes, greatly due to human activities, have seen an increase after the industrial revolution and have been happening for several reasons, such as increasing concentrations of greenhouse gases (water vapour, carbon dioxide, methane and nitrous oxide) and of particulate matter in the atmosphere. Over the last few decades, we've been witnessing the warming of the atmosphere and the ocean, the decrease of snow and ice, droughts, and the rise of sea levels and changes in its temperature, salinity and nutrient availability. All of these factors generate a domino effect, impacting all living beings and systems. Even though policy-makers are now aware of the current evolution and thoughtful actions have been designed to reduce negative effects, more efforts are needed to better understand and circumvent all negative outcomes.

Fungi are eukaryotic organisms ubiquitous on Earth. They can convert organic matter into carbon dioxide and small molecules – as decomposers; they can colonise plants, solubilising and delivering phosphorous, nitrogen, micronutrients and water – mycorrhizal; and they can cause disease in other beings – pathogens. Fungi are affected both directly and through the effects of organisms they are associated with. Since fungi play fundamental roles in nutrient cycling and exchange, and regulate key ecosystem processes, it is essential to understand how they are affected by such a large-scale event.

Global impacted areas: a fungal perspective

The effect of climate changes on fungi will, directly and indirectly, affect many areas. Here are some examples:

Agriculture. Around 90% of terrestrial plants benefit from being associated with mycorrhizal fungi. Plant-associated fungi play key roles in the plants' development, growth and health, and help them retrieve nitrogen from the soil. Chemical composition, pH, water content and organic matter are just some of the abiotic factors that characterise soils. These, called edaphic factors, are influenced by climate and influence several organisms such as fungal communities, causing biodiversity changes. Furthermore, abiotic stressors (e.g. increased temperature, salinity or carbon dioxide concentrations and



Temperature data in the past few decades. Grey line, annual mean; black line, lowess smoothing. NASA's Goddard Institute for Space Studies

Aspergillus niger, stereomicroscopy. Bar, 100 µm. Marta Filipa Simões

changes in water availability), which increase with climate change, disrupt mycorrhizal associations and can, in turn, influence vital agricultural aspects like irrigation requirements, crop rotations, optimal crop timing and the propensity for crop contamination with fungal phytopathogens.

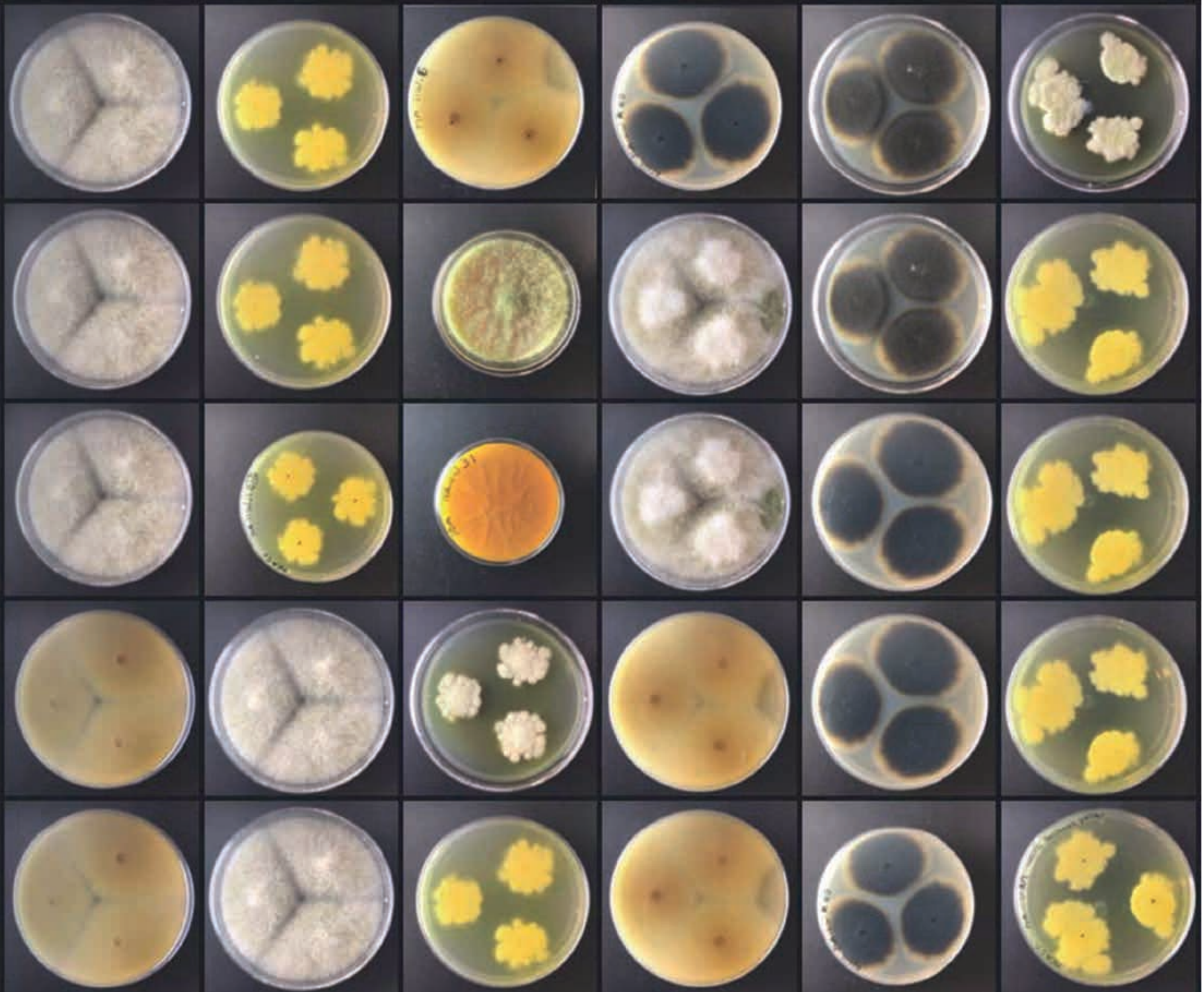
Current estimations point to a coupling of increase in global temperatures with a future increase in the relative and total abundance of soil-borne potential fungal phytopathogens from the genera *Alternaria*, *Fusarium*, *Venturia* and *Phoma*. When exposed to high carbon dioxide concentrations and high temperatures, *Fusarium verticillioides* – a phytopathogen of maize – becomes more resilient and suffers changes in its gene expression and phenotype for the production of toxic secondary metabolites, leading to an increased ability to cause infection. Indeed, contamination with mycotoxins (low-molecular-weight and toxic secondary metabolites) impacts the geographical distribution of many essential crops (e.g. cereals). As an example, studies have shown that maize crops in Kenya will be largely affected in the coming decades with increasing contamination of aflatoxins, a group of carcinogenic mycotoxins. Many phytopathogens can ruin crops and lead to major economic losses. Therefore, agriculture-based economies will also have to change and adapt to survive.

Food safety. Food and feed are often contaminated by toxigenic fungi and mycotoxins, both in pre-harvest as well as in post-harvest scenarios. Moreover, different mycotoxins tend to be associated with specific contaminations which are associated with specific types of food. Such contaminations affect food sources, animal feed, nutrition and therefore health.

Aflatoxins are commonly produced by *Aspergillus* spp. and are usually found in milk, eggs, cheese, cereals and nuts. Changes in climate can lead to acute aflatoxicosis and deaths from the consumption of contaminated food crops. Ochratoxin A (OTA), another foodborne mycotoxin, affects cereals, dry beans, peanuts, cheese, coffee, cocoa, dried fruits, grapes and wine. Climate change has been reported to increase fungal colonisation in grapes, which consequently increases the contamination of OTA in both grapes and derived products. OTA is nephrotoxic, with health risks for humans and other animals.

Biodiversity and ecology. Mycorrhizal fungi can also shield plants against extinction, facilitating or retarding the dispersal of plants from unsuitable environments, alleviating the effects of abiotic stressors or enabling these plants to adapt to new climates. Endangered plants might have their own specific mycorrhizal community, and selected fungal inocula could help promote their growth. Plus, with changes in ecological niches, fungal biodiversity will change, as well as its influence on its surroundings.

The mycorrhizal black truffle, *Tuber melanosporum*, is usually found in regions with a Mediterranean climate. It grows underground, in soils with high limestone content, in a symbiotic relationship with tree roots. While it can develop naturally, a large industry is dependent on its cultivation in chalky soils. However, this Mediterranean habitat has been



Fungal colonies grown in Petri dishes. Marta Filipa Simões

affected by drought for some time, reducing truffle yields. Therefore, in a trial to find alternative habitats, more suitable than its native one, it was found that *T. melanosporum* grows well in the northern maritime climate of the British Isles, the farthest north that the species has ever been found.

In some cases, when facing harsh droughts, some fungi, such as lichen-forming fungi, black fungi and yeasts have been found to survive on the surface of rocks, especially in drylands. These stable endolithic habitats offer some protection against temperature and radiation (ultraviolet and solar) and some degree of water retention. These fungi can colonise several different types of rock in both hot and cold areas. This attests to their impressive capability to adapt to extreme conditions.

Health. Overall, we have been observing more emerging fungal pathogens related to climate change, and this tendency is expected to continue.

For example, after the 1970s there was a rise in the rate of infection caused by *Talaromyces marneffei* (previously called *Penicillium marneffe*i) that occurs mainly in immunocompromised hosts. This is a thermally dimorphic fungus, able to grow as filamentous fungi or unicellular yeast-like fungi depending on the habitat's temperature, is endemic to Southeast Asia and China, and not found in temperate regions. It is considered an emerging pathogen.

Aspergillus flavus, another important pathogen of maize, when exposed to high carbon dioxide concentrations and high temperatures, produces higher amounts of the carcinogenic mycotoxin aflatoxin B_1, with an increased risk for human and animal health. In this case, the genes involved in the aflatoxin biosynthesis get activated earlier in the fungal life cycle; because this species is highly resilient to all climate stressors, it has its life cycle altered (higher lag times) when exposed to those stressors. This leads to a higher accumulation of aflatoxin.

Candida auris, a drug-resistant yeast first isolated in 2009 from a human ear, has also been emerging as a cause of disease in many different countries. The widespread use of antifungal drugs tends to contribute to the development of resistant species, but in this case, the resistance and virulence of this species seem to be associated with the adaptation to new climate conditions, and therefore its pathogenicity is directly linked with climate change.

How are fungi affected?

Fungi are very resourceful organisms, and abiotic stressors generated by the climate push them to develop and create their own ways of surviving the new realities. Adaptations have been reported on many levels: genetic, life cycle and sporulation, behavioural and metabolic. In addition to the adaptations described in the sections above, other alterations reported are thickening of walls of spores, allowing a higher resistance to temperature and water changes; melanisation, improving resistance to desiccation; formation of rhizomorphs, structures that allow for an easier way of transporting nutrients and water; appearance of jelly fungi, fungi with a gelatinous texture that allows them to survive periods of dry weather; and formation of sclerotia and other dormant structures, under which fungi can stay for long periods or until suitable conditions are met.

Furthermore, climate changes can alter the structure of fungal communities and may favour fungi over other organisms. One of the reasons for this is the acidification of soils that tends to inhibit certain micro-organisms and favour fungal growth up to certain pH values. This could then have a dramatic effect on the emission and sequestration of carbon dioxide and lead to positive feedback that translates into an acceleration in climate change.

Summary and future perspectives

Many predictions have already been made and many studies have been developed to better understand the consequences of climate change; however, there are still many knowledge gaps. We need more studies and research in order to better plan our future actions and adapt to the changes we cannot prevent or avoid. Understanding fungal mechanisms that allow extreme-tolerant and extremophile fungi to thrive and be metabolically active in harsh environments might help us to put in place adaptation measures and better plan our actions on Earth.

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Marta Filipa Simões is a postdoctoral fellow of astrobiology. Her research is focused on fungal ecology and biodiversity in environmental analogues to outer-space conditions, bioprospection and application of filamentous fungi, and fungal growth containment and exploitation to our needs in conditions similar to outer-space.

On a typical day in this position, what do you do?

There is no typical day at my work. Most of the time, I start by checking my emails and agenda. Then, from there until the end of the day, many things can happen: lab work, fieldwork and sampling in exotic and extreme locations, meetings, writing, reading and preparing presentations. I usually finish my day by preparing a short to-do list for the next day.

What is the most rewarding part of your job?

Everything that offers me moments of awe, the huge diversity and amazing morphologies of fungal species. The novelty of all the discoveries I make in science (from my work and other researchers' work), the people I meet, places I get to visit and explore, and the different cultures and perspectives.

The increase in global aquaculture and the associated protists: opportunities and threats

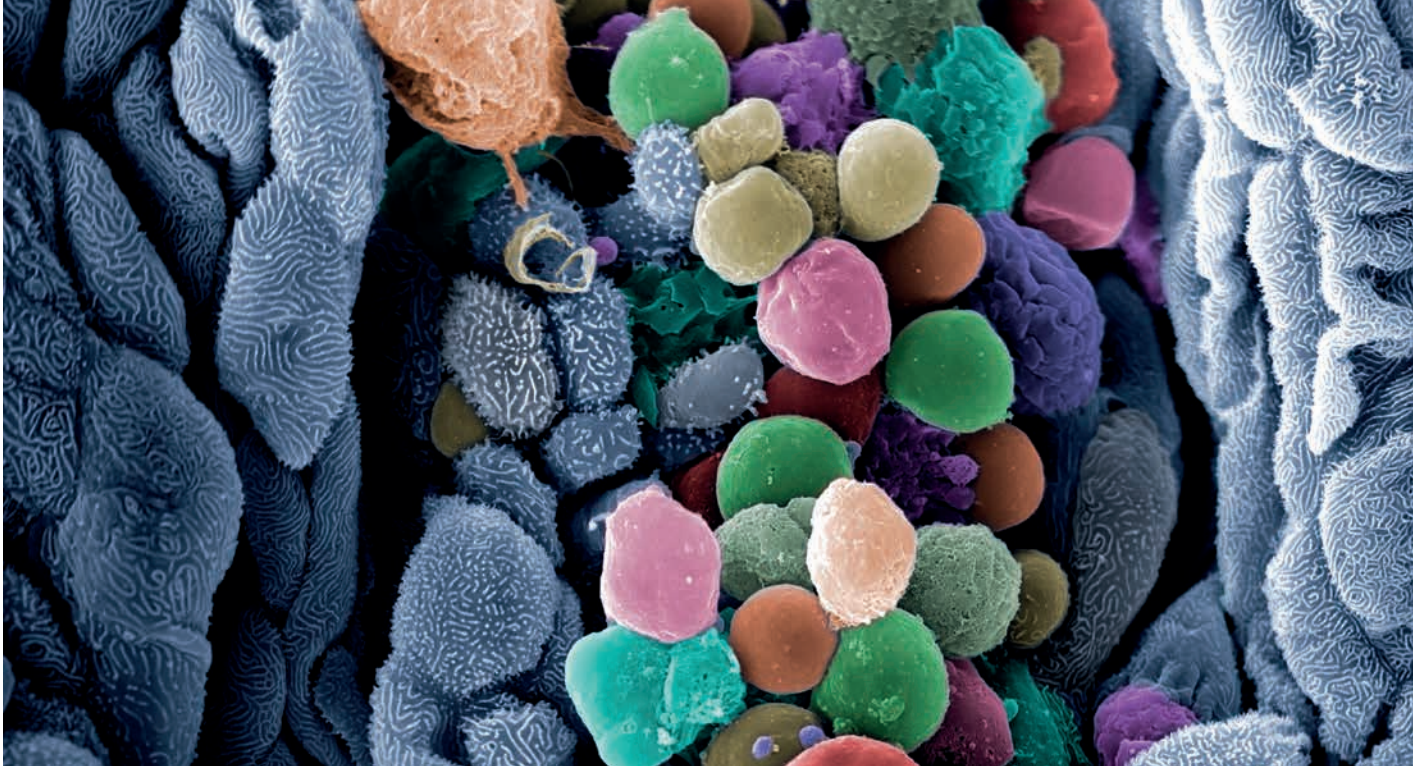
Sonja Rueckert, Fiona Henriquez, David Bass and Anastasios Tsaousis

According to the Food and Agriculture Organization (FAO; 2020), the contribution of aquaculture to the global production of finfish, crustaceans, molluscs and other aquatic animals had increased up to 46%, representing 114.5 million tonnes worth $263.6 billion, by 2018 compared with 26% in 2000, and is predicted to double by 2050. Besides aquatic animals, 97% of all aquatic algae come from seaweed farms and microalgal production is rapidly increasing. Among crustaceans, marine shrimps dominate the production and make them an important income source for developing countries in Asia and Latin America. In Europe, fish and molluscs dominate the industry. Atlantic salmon is the most important fish species with the largest proportion of export revenue, grown mainly in Norway and the UK. In the UK, aquaculture production was 197,000 tonnes worth $1.3 billion.

Planktonic protists: the basis of the food web

The term phytoplankton covers a huge range of organisms that form the basis of the food web, including protists e.g. algae, dinoflagellates, diatoms and bacteria such as cyanobacteria. A diversity of microalgae is grown in aquaculture hatcheries as a food source. There can be a fine line between phytoplankton being beneficial or detrimental in aquaculture. Algae such as *Chlorella* spp. and *Chaetoceros* spp. can serve as a food source as well as being able to utilise and remove overabundant nutrients, improving the water quality.

Aquaculture fish nets. iStock/Adokon



Coloured scanning electron micrograph of a salmon gill affected by amoebic gill disease (AGD). Magnification: x1,780. Jannicke Wiik-Nielsen/Science Photo Library

However, if the same species grow excessively, massive die-off events can lead to oxygen depletion in the system, stressing and killing the farmed organisms. Certain taxa such as the dinoflagellates *Gymnodinium* and *Ceratium* can cause harmful algal blooms that lead to oxygen depletion and can release biotoxins. Other algae (including *Chlorella*) may act directly as pathogens of cultured animal stocks. A diversity of other protists presents a range of health threats to aquaculture, as described in the next section.

A broad diversity of protists is associated with diseases in aquaculture

Neoparamoeba (Paramoeba) species are found in marine environments and despite typically being free-living amoebae, they are known to cause amoebic gill disease (*N. perurans*) in ray-finned fishes and have also been isolated from diseased sea urchins and crabs (*N. invadens, N. pemaquidensis* and *N. branchiphila*). The ichthyosporean (holozoan) *Ichthyophonus* is associated with cardiac pathology and other tissue tropisms in freshwater and marine fish. Flagellates are also known to be important pathogens. *Ichthyobodo necator* causes ichthyobodosis on fish skin and gills. The dinoflagellate *Amyloodinium ocellatum* is an ectoparasite that causes marine velvet disease in both marine and low-salinity brackish waters, whereas *Ichthyodinium chabelardi* infects the eggs and larvae of several marine fish species. The ciliate *Cryptocaryon irritans* causes white spot or saltwater ich in many fish that live in temperatures between 15 and 30 °C. Its unrelated (but still ciliate) freshwater counterpart *Ichthyophthirius multifiliis*, which similarly shows low-host specificity, is a menace to the cultured and ornamental fish trades. Gregarines are widespread apicomplexans, some of which infect shrimp. Two main genera are distinguished, *Nematopsis* and *Cephalolobus,* with a third, *Paraophioidina*, only described in cultured post-larvae of whiteleg shrimp. The ascetosporeans *Marteilia*, *Haplosporidium* and *Bonamia* (Rhizaria) are problematic for both production and trade in marine molluscs.

Many protists are associated with general tissue and organ damage. This is the case for both Microsporidia and the protist-like Myxozoa (which are highly specialised cnidarians and include many parasites of fish and other vertebrates, including *Tetracapsuloides bryosalmonae*, the causative agent of proliferative kidney disease in salmonids). The microsporidians *Desmozoon lepeophtherii* and *Loma salmonae* are associated with proliferative gill disease in several species of salmon and rainbow trout. Interestingly, *D. lepeophtherii* also infects sea lice, to which fish in aquaculture can be vulnerable to infestations. *Nucleospora cyclopteri* is associated with plasmocytoid leukaemia in lumpfish; *Enterospora nucleophila* causes emaciative microsporidiosis of gilthead sea bream; and the microsporidian parasites *Enterocytozoon hepatopenaei* and *Enterospora canceri* cause diseases in shrimp and crabs, respectively. Microsporidians are frequently associated with emerging diseases in a wide range of hosts, which is partly explained by their ubiquity and high diversity in many environments, including situations in which aquaculture is being intensified.

The broader pathogenic context

Enterocytozoon hepatopenaei (EHP) infects the epithelial cells of the shrimp hepatopancreas and, since its incidental discovery in 2009, has emerged as one of the most impactful pathogens in (sub)tropical shrimp aquaculture. In Thailand alone, economic losses due to EHP have been estimated at >$230 million per year. It is implicated in sub-optimal growth disorders, other syndromic diseases and mortalities in shrimp, the aetiology of which has been associated with EHP's co-infection with other pathogens, including the Laem-Singh virus. EHP also makes shrimp more susceptible to bacterial (*Vibrio*) diseases, acute hepatopancreatic necrosis disease (AHPND) and septic hepatopancreatic necrosis. The interaction of apparently 'primary pathogens' such as EHP with other host-associated pathogenic agents and micro-organisms is likely a more important factor in pathogenesis and disease susceptibility than previously recognised, which has recently led to the development of the pathobiome concept, acknowledging the interaction of host and environmental factors with the diversity of host-associated symbionts. Many examples of pathobiotic systems remain to be elucidated; a recent example being the diversity of *Vibrio* species endosymbiotic within *(Neo)paramoeba perуans*, the causative agent of amoebic gill disease in salmon. In general, the diversity and roles of animal- and plant-associated microeukaryotes is poorly known and the accepted wisdom regarding their role in pathogenicity should often be questioned in the framework of a context-dependent 'symbiotic continuum' of pathogenic effects, rather than 'hard-wired' host–pathogen relationships.

Managing microbial threats in aquaculture should consider the multi-domain nature of pathogenic agents (both impactful 'notorious' and emerging pathogens may be viral, bacterial or eukaryotic, as demonstrated by the last 30 years of increasingly intensified and diversified aquaculture) and their interactions in the (often highly modified and unstable) aquaculture ecosystem. Our very incomplete knowledge of the diversity and role of microeukaryotes in these systems frustrates efforts to manage and ameliorate compromised host health in these systems and to design robust diagnostic methods. As exemplified by the recent and rapid emergence of EHP, many more pathogens are endemic to and likely to be favoured by these modified systems. Diagnostic techniques can only target what is known; therefore, rapid characterisation of emerging pathogens is essential, as is an understanding of the phylogenetic diversity from within which these arise.

The diversity and complexity of host-associated microbes present a related challenge to global biosecurity: movements of stock and traded goods can transfer both known and unknown pathogenic agents along with their hosts and associated media. From a more positive perspective, the potential for improved pre- and pro-biotic treatments will be

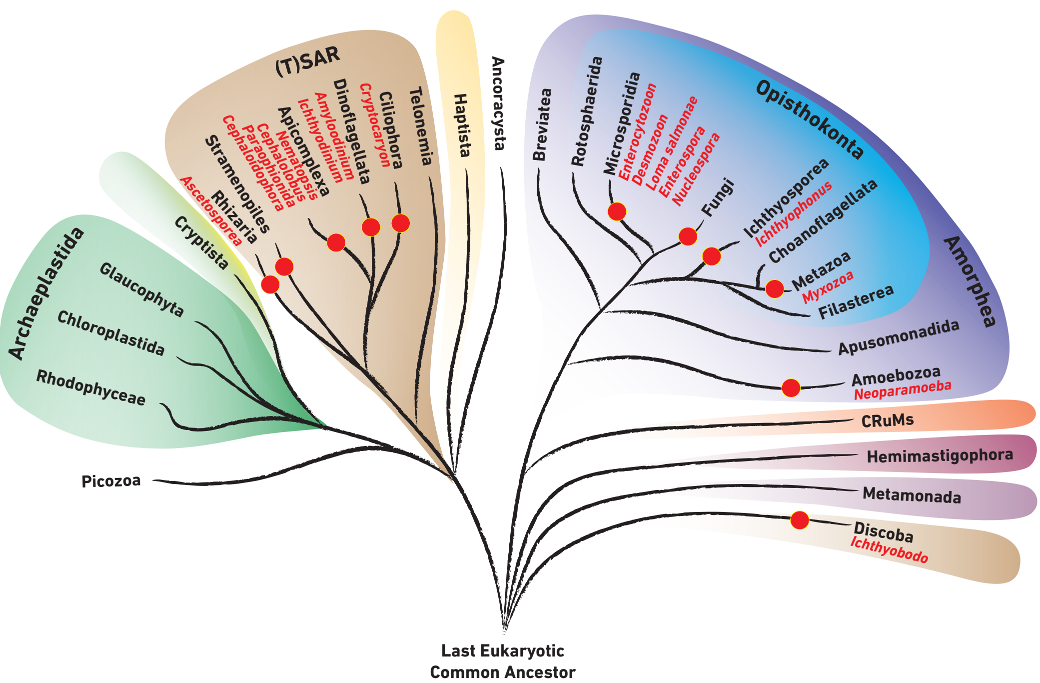


Fig. 1. **Representation of the eukaryotic tree of life, based on recent publications. Supergroups are indicated in bold, and lineages containing microbial parasites/ pathogens relevant to aquaculture are indicated by red dots and genus names. Notably, this diversity is distributed across most of the eukaryotic tree, even without aspiring to be comprehensive.** We would like to thank Kira More (University of Alberta, Canada) for providing us with the artistic template of the tree.

more easily realised when their constituent taxa are better understood and the role of microeukaryotes as feed for cultured stock, for example algae co-cultured in the pond environment or the (potential) role of microeukaryotes in shrimp culture biofloc systems, is ripe for development. Overall, a better understanding of, and ability to optimise, the ecological system within which stock is grown must inevitably focus on the most diverse and abundant organisms in aquaculture systems – i.e. microbial lifeforms – rather than a much narrower focus on a particular disease or other isolated element of a particular system.

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How do you see this field changing in the future?

Sonja Rueckert: Aquaculture is still one of the fastest-growing food production industries, and protistology is emerging as a major field of study. This is not only due to their critical participation in relevant food webs and feed supply for aquaculture, but also because protist ecology is changing in response to climate change. We have already identified a number of disease-causing protists, but there will likely be an increase in protists' pathogenic potential and/or their ability to harbour other potential microbial pathogens through parasitism or endosymbiosis.

What advice would you give to someone starting in this field?

Sonja Rueckert: Protistology in aquaculture is a diverse field. Besides gaining knowledge of relevant species and groups of protists, networking with individuals in the industry and understanding what the challenges in aquaculture are is important when starting in this field.

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All authors are elected committee members of Protistology-UK, a society that aims to promote the study, teaching and dissemination of all aspects of protistology, from ecological to medical and from sub-cellular to population studies.

Since 2018, Protistology-UK and the Microbiology Society have formed a partnership to bring together and share knowledge between communities for the benefit of their memberships.

More information about the authors and news regarding the society can be found at **protistology.org.uk**.

Microbes in icy ecosystems

Arwyn Edwards, Jarishma K. Gokul and Sara M.E. Rassner

The coldest parts of our planet are the fastest warming. Glacial ice locks away 70% of all fresh water, but if just a little of this ice is lost to the sea it threatens low-lying lands. A wealth of measurements, models and media attention speak to this intertwined fate of climate, ice and coastlines. But glaciologists found themselves unable to explain exactly how phenomena considered purely physical, ranging from rock weathering underneath glaciers to the melting of snow and ice surfaces, worked in the constant cold. Realising, at the turn of this century, that glaciers are ecosystems and microbes thrive from the top to the bottom of glaciers changed everything.

The birth of a glacier starts with a single snowflake. High in the atmosphere, ice-nucleating bacteria and dust catalyse the formation of the snowflakes themselves. Other microbes are washed out from the atmosphere or arrive in wind-blown dust. With a suitably long incubation period of a decade or more, accumulated snow is transformed from delicate crystals to hard glacial ice. This co-culture of microbes and ice crystals results in the entombment of microbes in the ice of glaciers. Globally, this represents a vast pool of microbial biomass almost a hundred times larger than in rainforest soils. But life in this icy jungle persists at a glacial pace, entrained in the flow of ice, sustaining itself in the microscopic voids between ice crystals for millennia. Viable bacteria have been recovered routinely from the deepest ice cores. The genomic diversity of this deep-frozen culture collection has barely been mapped, so our understanding of the adaptations required for long-term survival is limited.

Life beneath thousands of metres of ice seems vibrant in comparison. In the beds of glaciers and ice sheets, where ice rests on rock, life prevails in perennial darkness and in freezing temperatures, with nearly no nutrient availability. Some bacteria consume leftover soil carbon trapped by the last ice age, while other microbes turn to lithotrophy, respiring iron and sulfide weathered from traces of fools' gold. Others still use the hydrogen released from bedrock ground down by the ice. Crucially, an active methane cycle is present in the dark depths of these subglacial ecosystems. The balance between methanogenic Archaea and methane-oxidizing microbes can result in the net release of methane at the ice margin, further fuelling climate change, for methane is a potent greenhouse gas. In spite of the diversity of habitats and metabolisms within the geological ice cream sundae of crushed rock, ancient carbon, ice and bedrock of subglacial ecosystems, they are poorly understood environments because direct access to the bed of glaciers and ice sheets is challenging. The lakes, rivers and wetlands that form beneath ice sheets are teeming with microbial life. Using strict contamination-preventing precautions, researchers have successfully sampled two subglacial lakes – Whillans

The Perito Moreno Glacier, Santa Cruz Province, Argentina. Anton_Petrus/ iStock

and Mercer – of the hundreds found beneath the Antarctic ice. These drilling missions have described ecosystems inhabited by thousands of different kinds of bacteria and active methane cycles within lakes well-connected with the margin. Glacial science awaits the successful, clean sampling of subglacial lakes truly isolated for hundreds of thousands of years to understand if and how life survives within them.

Squashed under its own weight, ice flows. After all, glaciers are essentially frozen rivers. As ice flows to warmer microclimates at lower altitudes, it begins to melt. Afforded plentiful liquid water, dissolved nutrients and intense sunlight in summer, the surfaces of glaciers and ice sheets harbour ecosystems driven by photosynthesis. Sandwiching photosynthetic pigments and products at the interface between glaciers and the Anthropocene atmosphere creates a paradox. As life thrives here by fixing carbon dioxide from the atmosphere, its conversion into coloured biomass hastens the death of glaciers. Ice and snow reflect most solar energy, but dark biomass absorbs this energy, melting underlying ice or snow.

Aristotle first described red-stained snow as a biological phenomenon. We now recognise that this is in fact caused by *green* algae which accumulate red carotenoid pigments as protection against the harsh effects of the sun on snow. These algae are the charismatic microflora of the glacial ecosystem, colouring swathes of the snow-surface pink. On bare ice, glacier algae face similar challenges from intense solar radiation. Their solution is the concentration of intense brown or purple pigments as sunshades atop their chloroplasts. Glacier algae belong to a group of organisms between the green algae and ancient land plants. It is likely they have been inhabiting glacier surfaces for hundreds of millions of years, but their importance has only been realised in the last decade. The Greenland Ice Sheet, the largest mass of ice outwith Antarctica, is heavily colonised by glacier algae at its southwestern edge – the Dark Zone. Visible from space, we fear this biological darkening is pushing the Greenland Ice Sheet over the edge.

The most elegant ecosystem of all sits within the ice surface: small potholes called cryoconite holes that litter the ice surface, representing remarkably stable microenvironments. Dark debris – cryoconite – coalesces on the ice surface, encouraging melting and resulting in downward growth of the hole until it reaches a depth where the melting rate at the hole-bed matches that of the surface. Coincidentally, this depth is where optimal levels of sunshine reach the cyanobacteria, fuelling intense carbon fixation. Cryoconite forms by filamentous cyanobacteria ensnaring dust particles within their extracellular polysaccharides. Cryoconite granules often exist as lawns the thickness of single granules, increasing the surface exposed to sunlight. The simple experiment of overloading cryoconite holes by spooning in extra cryoconite dramatically alters the shape of the cryoconite hole until the hole bed can accommodate a single granule lawn once again.

Cryoconite holes are essentially photosynthetic micro-reactors in the ice surface. High rates of photosynthesis within the cryoconite granules sustain biodiverse and abundant microbial communities containing bacteria, fungi, protozoa and even tardigrades. In the balmy porous ice surfaces of Arctic or mountain glaciers, nutrients and cells are free to flow between holes, whereas in the deep cold of the Antarctic, cryoconite holes typically survive under thick ice lids for years to decades as self-contained biotic and abiotic islands. Even in the most austere of these glaciers, where katabatic winds scour and polish the perennially frozen blue ice, the surfaces are pockmarked by cryoconite. The most feasible source of microbes in these sub-zero ice oases are cells entrained in the polar ice for millennia. While intense predation of cryoconite bacteria by viruses results in the leakage and recycling of

Algae in melting glacial ice in Antarctica. Ashley Cooper/Science Photo Library

carbon to the extent the cryoconite food web is truncated, these are without doubt the microbial oases of the glacier surface.

Ultimately, all these microbes and the carbon and nutrients they cycle help seed the soils formed as glaciers recede and the rivers and coasts fed by glacial meltwater. As glacier microbiologists, we heed the changes of the coldest parts of our planet and face up to the realities of glacier loss over the next decades. We are sometimes asked if we might be able to engineer these ecosystems to reduce their melting potential. As we learn more about the diversity and evolution of glacier microbes, perhaps the better question is if we can engineer our ecosystems to sustain these enigmatic life forms.

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Acknowledgements

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What do find most enjoyable about your work?

Arwyn Edwards: From coronaviruses to cryoconites, microbiologists are working on crucial aspects of some of the greatest challenges facing us as a species and a planet. But we also have the opportunity to train future microbiologists to address these challenges. The balance between the two is compelling.

What inspired you to become a microbiologist?

Arwyn Edwards: In 1995, my Year 7 Science teacher at Ysgol Dyffryn Teifi in Ceredigion got hold of some agar plates and convinced the class to 'donate' some microbes. Even though she sealed the plate carefully, this is not an experiment I would repeat in such settings today! However, the diversity of colonies that grew was amazing. It was my first peek at an invisible world which has been fascinating to explore ever since.

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Arwyn Edwards is a Senior Lecturer in Biology and Director of the Aberystwyth University Interdisciplinary Centre for Environmental Microbiology. His research in planetary health microbiology focuses on the interactions of cold-region microbes with climate. When not in Aberystwyth, he can usually be found sampling microbes in the polar regions. Arwyn has been a member of the Microbiology Society since 2003.

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Jarishma Gokul is a Researcher in Microbiomes and Lecturer in the prestigious next Generation of Academics Program (nGAP) at the University of Pretoria, South Africa. Her research to date covers the microbial ecology of polar and temperate terrestrial and marine landscapes, as well as the seed–soil–plant–food–human microbiome nexus. Jarishma has been a member of the Microbiology Society since 2014.

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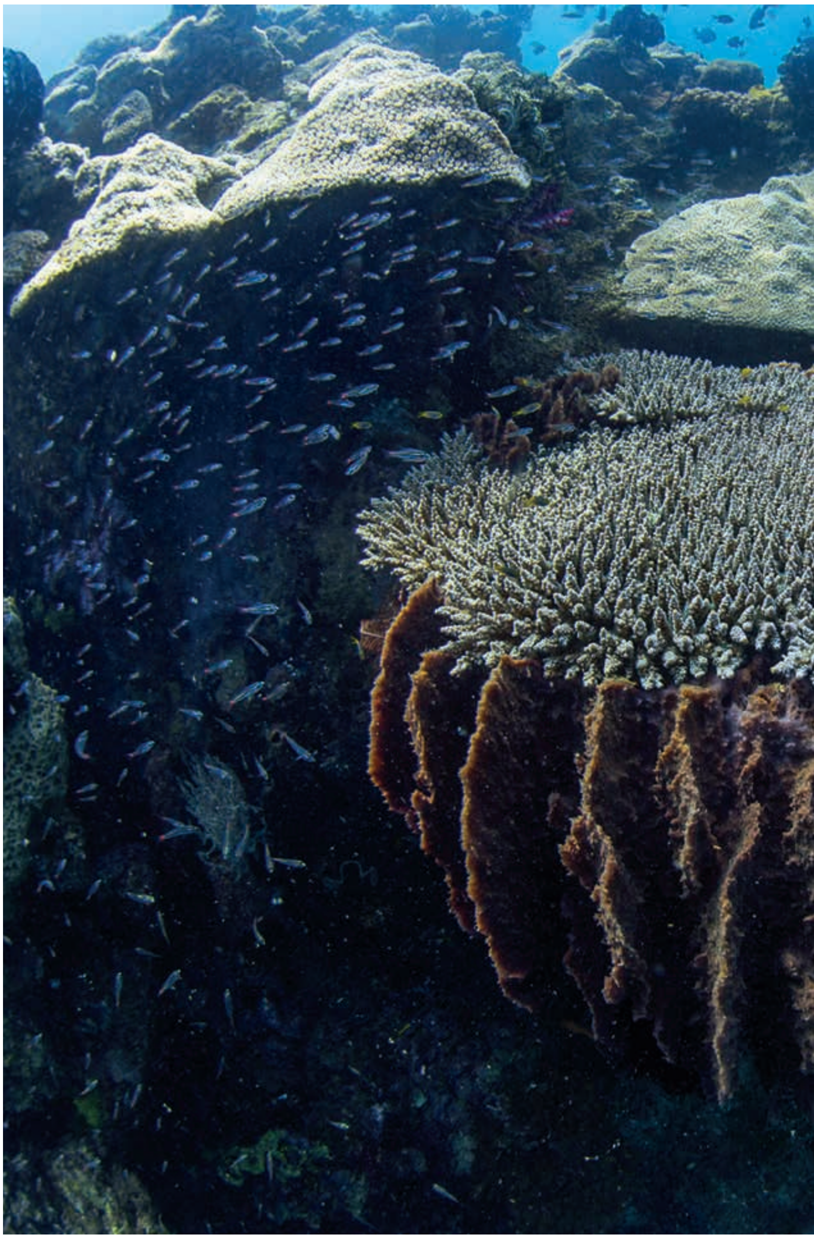
Sara Rassner is a Postdoctoral Research Associate on the NERC-funded project MicroMelt at Aberystwyth University. Her research is focusing on the interplay between microbial community interactions and the surrounding environment, both on glaciers and in other cool places. Sara has been a Microbiology Society member since 2017.

Microbiology of coral resilience – with a little help from my friends

Christian R. Voolstra

It's been a long way since I became considered a coral microbiome researcher. And unlike many of my friends and colleagues, I am not a traditional microbial ecologist delving into the field of genomics. Quite the opposite actually. Traditionally, I am a genomicist. I like data, big data, and I like computers. I like systematic, large-scale approaches and figuring out analytical routines that work across a large set of samples or data. But I also like going out to 'disconnect', quite literally, from the modern world of tech. Since I was a kid, I have felt drawn to the mystic of the ocean – such a vast place, still less explored than the surface of the moon, with many exciting discoveries to be made! I grew up academically when it actually became feasible to look at all the genes or proteins of an organism at the same time – in parallel – and when genome sequencing was no longer a pipe dream, reserved for a few model organisms we value dearly, but became considered a valuable foundation for many research avenues. Having had my share of work with the fruit fly and the mouse during my Master's and PhD studies, only as a postdoc I returned to my passion for the ocean by making it part of my scientific career; this, by the way, comprised a considerable chunk of my lifetime, so I knew I'd better do what I love in order to love what I do. This time around, however, I brought an entire arsenal of model system genomics with me to study the vast range of symbiotic interactions occurring in the busiest and most biodiverse marine ecosystems of them all – coral reefs.



Anna Roik

Coral reefs

If you study coral reefs, you have to pick your choice. Literally 1000s of species flourish in healthy coral reefs – they are teeming with life and in fact feel more like a busy city. This is, after all, a well-justified comparison, since coral reefs constitute the largest biogenic structures on earth. So large that you can actually spot them from the moon. Well, the

Corals provide the structural and spatial framework of reef ecosystems through their calcium carbonate skeletons, which serves as a habitat for a myriad of species and can resemble the complexity and busyness of big cities. Anna Roik

Great Barrier Reef in Australia that is, which is the largest reef system in the world. Close to a billion people depend on coral reefs for their livelihood, be it as a source of protein, for coastline protection or as a source of income (from tourism for example). For me, it was always clear that my pick is corals, quite literally the foundation species of these ecosystems. To the untrained eye, they might be mistaken for colourful rocks, but they are actual sessile animals that 'learned' to live like a plant. This is because they host little plants, i.e. microalgae called Symbiodiniaceae, inside their tissues that provide them with sugars from photosynthesis. The symbiotic relationship is so successful that it covers close to 100% of the coral's energy needs and provides the basis for corals to build calcium carbonate skeletons. These in turn give rise to the three-dimensional spatial structure of reefs that then provide habitat for the myriad of species one can find.

The coral metaorganism

But the story doesn't end here. Besides Symbiodiniaceae, coral animals associate with many other organisms, most notably bacteria, but also fungi, other algae, protists, archaea and viruses that all contribute in one way or another to the biology of corals. This is why we speak of coral holobionts to acknowledge that it takes the cooperation of many organisms to make a reef. Coral biologists have understood this for quite some time: that symbiotic relationships with micro-organisms are the building block of success for corals. But it wasn't until about a decade ago that it was connected to the bigger notion that the metaorganism – the organism of organisms, the sum of the multicellular host and its microbial associates – constitutes the functional biological unit one


Anna Roik

must consider. Biology at large came to acknowledge that microbes matter, not only in their own right but as symbiotic associates of animals and plants. This we also knew for quite a while. Think about the plant–rhizobia relationship: literally a textbook example of how soil bacteria engage with plant roots to produce nitrogen in return for receiving nutrients. What changed is the notion that pretty much all life is symbiotic: metaorganisms are rather the rule than the exception. Concomitant to the understanding that bacteria extend the capabilities of their host organisms is the notion that these associations are, to a degree, flexible. Hence, one can acquire new traits through association with novel microbes and potentially adapt to a changing environment, notably at a much faster rate than by means of (host) evolution. All that it takes is a microbial changeover.

Coral bleaching and climate change

Which brings us back to coral reefs. Life seems peachy as a coral, but the reality is that corals have faced unprecedented loss over recent decades. We have lost about half of all coral. Part of it is due to local factors, such as overfishing, pollution and coastal development. But the symbiotic relationship between corals and their microalgae is extremely sensitive to increases in water temperatures past their historic summer mean. Extended periods of warming lead to so-called coral bleaching, i.e. the physical whitening of coral animals due to the loss of their colourful symbiotic microalgae. Without their algae, corals lose their source of food and eventually die of starvation. This is a phenomenon that was pretty much unknown before the 1980s, at least with regard to widespread bleaching. Nowadays, climate change is fuelling ocean warming and has led to three global mass coral bleaching events over the last two decades. The fear is that we may be at risk of losing reef ecosystems at large under the ongoing projected warming. Ironically, and devastatingly, even the projected curbing of global warming to under 2 °C may be too warm for many corals to survive. So, we need to do something about it.

Microbiology of coral resilience

It's understood that bleaching is intimately linked to the microbes that coral associates with, most prominently to the type of Symbiodiniaceae microalgae. Hypothetically, the loss of Symbiodiniaceae during bleaching provides an opportunity to associate with novel, more thermotolerant microalgae, known as the 'Adaptive Bleaching Hypothesis'. And indeed, microalgal turnover can be observed in the wild. However, such novel associations typically only last for the duration of the thermal anomaly and return back to their original configuration shortly thereafter. Such high 'symbiont fidelity' may be explained by the long evolutionary history that both organisms share, which may lead to co-diversification if not co-evolution. In layman terms, the coral and the microalgae have learned to live with their partner's peculiarities and it may not be so easy to engage in new relationships. The case is different, however, for bacteria. The majority of coral-associated bacteria do not reside intracellularly, but rather tend to be found in the so-called surface mucus layer, which provides protection to the coral tissue, while allowing gas and metabolite exchange – very much like the mucosal surface of our mammalian guts. In this space, association is far less committed, and we now know that the microbiomes of many corals adapt when exposed to thermally stressful environments that can turn bleaching-susceptible into more resilient coral. Such 'microbiome flexibility' is fuelling the promise that adapting with microbial help to more strenuous environments may provide an alternate, more rapid route to organismal adaptation. Indeed, most recently, manipulation of coral microbiomes, through the addition of native beneficial bacteria, demonstrated the ability of coral probiotics to mitigate bleaching and their potential as a 'therapy' to minimise coral mortality. While I witnessed the increasing deterioration of coral reefs in my own lifetime, it is reassuring to see a potential treatment emerging. Many open questions remain, but one thing is for certain: we are metaorganisms in a bacterial world, providing tremendous yet to be explored opportunities.

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Dr Voolstra studies coral metaorganism function and adaptive capability combining ecological, environmental, microbial and molecular approaches. Dr Voolstra's most recent research has particularly advanced knowledge on how the bacterial microbiome contributes to coral-bleaching susceptibility and stress tolerance, the elucidation of fine-scale genetic differences between microalgal symbionts as well as the development of field-deployable standardised phenotyping methods to better understand biological and environmental traits that support coral resilience.

What parts of your job do you find most challenging?

First off, I feel immensely privileged to be able to do the work that I do, interact with so many smart and motivated people and get to know and experience parts of this world that few get to see. Probably what I find the most challenging is how to make an actual real-world difference. Research is gratifying, but we have a responsibility to step out of the 'ivory tower' and participate in the societal discussion about what world we want to live in and how a world needs to look like that we (and future generations) can live in. I am challenging myself to find better and more ways to engage in this.

What do you see as your greatest achievement?

I think I am good at enabling people and advancing methods/approaches, really connecting dots of things that are partially there but need some further push to 'become mainstream'. I am proud of SymPortal (**symportal.org**) because it standardises how we analyse the microalgae (Symbiodiniaceae) that coral associate with. Similarly, the Coral Bleaching Automated Stress System (CBASS) implements standardised diagnostics for coral bleaching susceptibility and is experiencing increasing popularity. Last, the notion of 'microbiome flexibility' provides a framework to interpret the capacity for microbial manipulation to support coral resilience. In all these cases, my main job was providing the intellectual space, academic freedom or financial means to either support incredibly talented people or to connect the lines of existing prior work/research.

Climate change: microbes to the rescue?

André Antunes

Since the industrial revolution, human activity and the ongoing burning of fossil fuels has drastically increased the concentrations of greenhouse gases. As an example, carbon dioxide (CO_2) concentrations, which ranged from 180 to 280 parts per million (ppm) for most of the last hundreds of thousands of years, increased to 400 ppm in the period between 1970 and 2010 and are predicted to rise to up to 700 ppm by the end of the century. Such an increase is leading to an unprecedented climate crisis of global proportions, which includes global warming, sea-level rise, extreme storms and flooding, droughts, wildfires and desertification. The discussion on climate change has been mostly centred on its effect on human populations, particularly on how rising seas might affect urban coastal areas and how warmer weather might affect the sustainability of food production. Some of the discussion has also focused on wider ecological impacts and large-scale ecosystem disruption resulting from the change in oceanic currents or ocean acidification. Microbes form the basis of all life on Earth, yet very little thought has been given to the interactions between microbes and such a global-scale event.

The global impact of microbes

Unknown for a long period of time, the global impact of microbes is now widely recognised. Microbes are the dominant life forms on our planet by far; they also control and condition global-scale geochemical cycles (namely of carbon, nitrogen and sulfur), which are essential to all life on Earth.

The reach and impact of microbes extends from the oceans and continents up to the air that surrounds us. Despite the fact that the atmosphere constitutes the largest fraction of the biosphere, studies on atmospheric microbial diversity and distribution remain surprisingly sparse. The dispersion of microbes through the atmosphere is very relevant from both an epidemiological and an ecological perspective. Furthermore, atmospheric microbes also seem to play a role in climate patterns and change, most notably in bio-precipitation. Bacteria such as *Pseudomonas syringae* have been shown to act as nucleating centres that are directly implicated in the formation of rain, hail or snow. The exact dynamics of this interaction between airborne microbes and aerosols, clouds and precipitation is slowly being unveiled and promises to provide important new insights into climate, the global impact of microbes and a new range of potential applications. There is still a lot to investigate in this field.

Microbes to the rescue?

CO_2 sequestration

Curbing CO_2 emissions is seen as the preferred way of limiting climate change. This relies on the development and adoption of new technologies, use of alternative fuels and wider modification of cultural habits. Given that this is a slow-paced approach, it might not be quick enough to avoid climate catastrophe. Several authors thus propose to replace or complement it with mechanisms to capture CO_2 as an alternative way of controlling its levels in the atmosphere.

Within capture approaches, geological sequestration is the leading technology and is seen as the most useful for quickly storing large volumes of CO_2 by pumping it into the subsoil or under the ocean. However, conventional methods for CO_2 capture or sequestration are frequently inefficient, expensive and hazardous and lead to secondary pollution. The use of microbially mediated processes is seen as a suitable alternative and has been gaining increased traction.

Many microbes are able to fix CO_2 and convert it into higher-value bioproducts, such as biofuels. There are even some interesting test-pilot studies looking into setting up

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microbial carbon capture cells combining CO_2 capture with biofuel and energy production. On a parallel path, several microbes capture CO_2 by accelerating the carbonation process, which converts carbon dioxide into calcium carbonate, usually via a combination of the enzymes carbon anhydrase and urease. This process provides a comparatively clean and more sustainable source of calcium carbonate ($CaCO_3$), when compared with synthetic production, and has been receiving considerable attention given its widening range of applications (which also include civil engineering, art restoration, soil improvement and bioremediation). Such microbially induced calcite production is a relatively common phenomenon but remains poorly understood. It has been reported in a variety of species but, so far, most studies and applications have relied on the use of a handful of species of the genus *Bacillus*, *Sporosarcina* and other closely related genera.

The capture of CO_2 with sequestration in the form of carbonate biominerals might prove particularly insightful and useful. Biogenic carbonates are increasingly used for producing bio-concrete and could eventually lead to the reduction of regular concrete production. It is worth highlighting that, after water, concrete is the most used material in the world and its production is very energetically costly, making it one of the largest CO_2 emission sources.

Other greenhouse gases

While climate change is most frequently perceived and discussed as an outcome of the increase in CO_2 levels in the atmosphere (due to its high abundance), CO_2 is not the only relevant greenhouse gas. Methane, nitrous oxide and some halocarbon gases are also on the top of our concerns given their rising concentrations, global warming potential and atmospheric lifetime. Despite their lower concentrations in the atmosphere, these gases lead to a much more pronounced greenhouse effect than CO_2, ranging from 25 times higher values for methane (CH_4) to up to more than 10,000 times higher for some halocarbon gases.

Methane is a particularly destructive greenhouse gas, as it is expected to naturally increase with the rise of temperatures (a process known as positive climate feedback). Anthropogenic methane emissions are heavily linked to agriculture, more specifically with livestock. Ruminants are massive producers of methane as part of their regular digestive process: each ruminant produces an average of 250–500 litres of CH_4

Coloured scanning electron micrograph of *Pseudomonas syringae*. Magnification: x2,600. Dennis Kunkel Microscopy/Science Photo Library

per day! Our understanding of microbial metabolism and physiology allows us to devise strategies that help us to control this issue, namely by the use of probiotics and food supplements that lead to changes in the gut microbiome of ruminants and reduce methanogenesis.

Likewise, hopes to use microbes to mitigate nitrous oxide (N_2O) levels have been boosted by the ongoing discovery of novel groups of bacteria and archaea capable of reducing this compound into harmless nitrogen (N_2). There are also some interesting results on microbial degradation of halocarbon gases, although their industrial production and emission are now severely restricted.

Global-scale change: beyond Earth

Despite being in its infancy, such a potential global-scale use of microbially assisted planetary engineering to tamper with our atmosphere and climate could have a much wider reach. Several authors defend that future colonisation efforts on Mars will require some sort of terraforming, which will most likely rely on the use of microbes. Such global engineering would aim to make the surface and climate of Mars more Earth-like and hospitable to humans.

It is worth noting that this topic raises some additional concerns both from a planetary protection perspective and from an ethical one. If life does exist on Mars, any type of human interference could lead to environmental catastrophe and collapse entire alien ecosystems. Even if there is no life on Mars, many defend that there should be an obligation to preserve its environmental conditions as much as possible.

Future perspectives and conclusions

Microbiology might well provide us with a sustainable solution to solve our current climate crisis, although caution is recommended. We need to increase our understanding of how microbes might be affected by climate change, anchored on community-level studies and mapping of biotic and abiotic interactions. Furthermore, there is an urgent need for more efforts focusing on microbial-based mitigation, with integration of bioprospection, new species discovery and characterisation, as well as the use of genomic-based exploration together with the potential use of genetic and metabolic engineering for improved results.

Further reading

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André Antunes is an Associate Professor and team leader of astrobiology at China's State Key Laboratory of Lunar and Planetary Sciences at Macau University of Science and Technology (MUST). He is an expert in microbiology of extreme environments, having specialised in deep-sea and high-salinity locations.

What do you love most about your job?

I love how microbes are connected with everything! Part of my current research focuses on the most exciting cross-disciplinary fields of microbiology: astrobiology and geomicrobiology. Both of them bridge the divide between very different fields of science, requiring me to be constantly engaged with researchers who have very different approaches and perspectives. This can be quite challenging, but I keep learning completely new things daily!

What's the best career decision you've ever made?

Rather than a single career decision, I would say that being open to new opportunities and avoiding getting too attached to my comfort zone were probably the most influential career options that I have made. I have moved frequently across the globe and had my ups and downs, like everybody else. Looking back on things, I think that all decisions that I made were eventually important in leading me to where I am today.

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Annual Conference Online 2021

Monday 26 April–Friday 30 April 2021
Digital event

At the end of April, the Society hosted its Annual Conference 2021, which was delivered online over five days.

Due to the continued prevalence of SARS-CoV-2, the cause of COVID-19, the event was delivered as a digital version of the Society's flagship annual meeting whose symposia and activities were designed to achieve the same scientific and networking objectives.

The event was a great success and consisted of symposia, workshops and fora from some of the world's most eminent microbiologists:

- 18 scientific sessions designed to demonstrate the impact and potential of microbiology in addressing important global challenges
- over 1,500 delegates
- 500+ e-posters
- talks from 80+ invited speakers
- one Hot Topic keynote: **The "post-truth" world, science and vaccinations** by psychologist **Stephan Lewandowsky** University of Bristol, UK
- nine Prize Lectures:
    - **Britt Koskella** University of California, Berkeley, USA
    - **Julian Parkhill** University of Cambridge, UK
    - **Martin Maiden** University of Oxford, UK
    - **Graham Hatfull** University of Pittsburgh, USA
    - **Elisabeth Bik** Harbers Bik LLC, USA
    - **Manu Prakash** Stanford University, USA
    - **Azra Ghani** Imperial College London, UK
    - **Martin Blaser** Rutgers University, USA
    - **Joan Steitz** Yale University, USA
- four sessions dedicated to professional development:
    - Careers in microbiology
    - Essential Skills: Entrepreneurship
    - Essential Skills: How to secure a fellowship
    - Teaching microbiology in higher education symposium

On-demand content

The scientific sessions delivered across the week are available on-demand for members and registered attendees until **4 June 2021**.

Journals

If you presented work at our Annual Conference Online 2021, why not submit your article to one of our journals to continue to support the work of the Microbiology Society and the microbiological community? Visit the Microbiology Society journals platform to find out more: **microbiologyresearch.org**.

Annual Conference 2022

Monday 4 April–Thursday 7 April 2022

Preparation is now well underway for our Annual Conference 2022, which will see the Society return to its in-person annual meeting format following a two-year hiatus due to the global health crisis.

The Society is delighted to be going back to Belfast and its wonderful International Convention Centre (ICC) that will host the organisation's flagship meeting. Abstract submission will open on **16 August 2021** and close on **10 December 2021**.

Destination Belfast

Belfast is the capital of Northern Ireland and home to the Microbiology Society Annual Conference 2022. Next year's event features an extensive programme designed to cover the breadth of microbiology, as well as professional development sessions, social activities and lots of face-to-face networking opportunities.

Belfast is a city rich in culture and history, and is the perfect destination if you are looking to extend your stay. Whether you enjoy historic landmarks, attractions or want to experience some new culinary delights, there is a lot waiting to be discovered. Popular Belfast attractions include the Titanic Museum, the Alexandra Graving Dock and Belfast City Hall, one of Belfast's most iconic buildings.

Accommodation

To support you in organising your accommodation, we will be providing links to our booking and accommodation services on the Annual Conference 2022 website.

Programme

The agenda is currently in production with our Scientific Conferences Panel to deliver an exciting and cutting-edge programme. Check the event website for further information (**microbiologysociety.org/Microbio22**).

To get the latest news and updates for this flagship meeting from the Society, follow us on Twitter **@MicrobioSoc** using the hashtag **#Microbio22**.

Dr Microbe/iStock

Focused Meetings 2021

The Society organises a varied programme of Focused Meetings each year that brings together those with shared scientific interests across the full range of microbiology topics. Following the cancellation of our physical events programme due to COVID-19, the Focused Meetings for this year will all be delivered as digital events. These are designed to promote the latest scientific research on key areas of microbiology.

Candida and Candidiasis 2021

21–27 March 2021
Digital event – **#Candida2021**

This seven-day meeting was hosted by the Society and delivered as an online event. It brought together the *Candida* research community to present the latest advances and ideas to empower major ongoing efforts to understand, treat and prevent *Candida* infections. It also presented the latest advances and ideas about the molecular mechanisms that underpin *Candida* pathobiology, the immunological responses of the host to the fungus and antifungal drug resistance.

Anaerobe 2021: The Microbiota and Beyond

15–16 July 2021
Digital event – **#Anaerobe2021**

The Microbiology Society is pleased to present Anaerobe 2021 in association with the Society for Anaerobic Microbiology. Anaerobic bacteria are predominant members of the normal human microbiota and well recognised as lethal pathogens. Aspects of their virulence, antimicrobial resistance and interactions with the human host will be highlighted during this Focused Meeting.

Avian Infectious Diseases 2021

15–17 September 2021
Digital event – **#Avian21**

Infectious diseases continue to threaten the sustainability, productivity and growth of the poultry industry worldwide and some present a risk to public health. Many are also present in wild bird populations, with the potential to spill over into domestic birds. This online meeting capitalises on the success of the previous Microbiology Society Focused Meeting entitled 'Pathogenesis and Molecular Biology of Avian Viruses' and expands the remit to include bacteria and parasites.

British Yeast Group 2021: The future of yeast research

7–9 December 2021
Digital event – **#BYG21**

This year's British Yeast Group Meeting will focus on the future of yeast research. The programme will feature assorted talks from invited speakers and will provide plenty of opportunities for early career researchers to present their work through e-poster presentations and offered oral presentations. The meeting will conclude with a stimulating discussion on the future of yeast research that will be chaired by Nobel Laureate, Sir Paul Nurse.

You can find information about abstract submissions, registration and other details for any of these events at **microbiologysociety.org/events**.

Scientific Seminar Series 2021

The Scientific Seminar Series is designed to reach a priority microbiology community to support it in disseminating knowledge across its professional networks. The events are designed as a regularly repeated series of short (typically 1–2 hour) online meetings.

SARS-CoV-2 and COVID-19 Seminars

Monthly

The Society is seeking to gain a greater understanding of ongoing and planned SARS-CoV-2/COVID-19 research in order to build national and international cooperation between virologists and the wider scientific community. These meetings are designed as a catalyst for information exchange and to extend the research network.

JMM Speaker Seminars

Monthly

A monthly seminar series from the *Journal of Medical Microbiology* (JMM) that is designed to disseminate high-quality and timely research from the journal's key authors. JMM is the go-to interdisciplinary journal for medical, dental and veterinary microbiology. It welcomes everything from laboratory research to clinical trials, including bacteriology, virology, mycology and parasitology.

Careers Focus: teaching microbiology in higher education

During the 2018 Annual Conference, we hosted the Society's first Teaching Microbiology in Higher Education Symposium, which aimed to bring together those involved in teaching to share practices, exchange new ideas and discuss issues affecting the teaching landscape. Since then, we have aimed to create an environment where members can support each other in this area.

Recently, platforms like this have become even more important to share an evolving way of teaching during a time of reduced face-to-face interaction with both students and colleagues. As we reflect on some of those changes, here are some of the lessons learnt and things to consider.

Maintaining student engagement

Engagement is essential in allowing students to digest and apply taught studies; however, it can be difficult to interpret just how engaged students are when teaching online. Creating stimulus during lectures, for example via chat functions and using polls, can help in reading the audience and understanding if you're engaging your students with key take-home information.

The role students play in each other's learning is also important to bear in mind. With the absence of reassurance from their peers, students may feel less supported and confident in their approach or ability. Peer-feedback can be incorporated in many ways, such as allowing time for students to present related research to each other. This can allow them to analyse their own research from a different perspective and develop their reflective practices. Projects where students are encouraged to work in small groups can also create a sense of social belonging and valued contribution.

Digital teaching

As we become more reliant on technology, you may wish to consider ways in which it can be incorporated to ease the learning of students. Convenience often enables students to focus on the task at hand or even go beyond the bare minimum. Everyday practices such as note-taking can be made convenient and efficient with Sketchnotes, for example – downloadable images that can be used to capture key concepts that may appeal to visual learners. Also, pre-picking resources for students and presenting them via QR codes rather than links may increase the ease with which students can access wider learning.

Facilitating learning without the burnout

With the extra workload that comes with remote teaching and the added pressures of working during lockdown, managing the demands of teaching and getting the most out of students whilst minimising burnout can be difficult.

When converting lectures and tutorials into online content, it is important to remind yourself that, in most cases, these types of content cannot replicate direct physical experience. It might also be worth reviewing learning outcomes and identifying which are essential and which are duplicated elsewhere, to minimise the unnecessary burdens. Managing expectations from the perspective of staff and student will enable you to feel a greater sense of control.

As we adapt to a new way of teaching, there are many learning opportunities that we can use in practice. The Microbiology Educators Network, a bi-monthly webinar series focused on allowing members to share current teaching experiences, was launched last year in response to supporting members teaching microbiology in higher education. You can watch past webinars to hear how others have navigated through challenges. You can also explore a range of teaching resources, including presentations from the annual Teaching Microbiology in Higher Education Symposium, on our website (**microbiologysociety.org/TeachingResources**).

Early Career Microbiologists' Forum update

Welcome to the first ECM Forum update of 2021. I would like to start once again by saying thank you to all the key workers that are working through this pandemic. Thanks as well to all the microbiologists who continue to be part of testing and vaccine rollout, and to those continuing to treat people in hospital. You are all doing incredible work and deserve the thanks of the whole country.

Robert Will

nensuria/iStock

The year began with the restructuring of the Society's Committees. The Committees that were (Communications, Policy, etc.) have been combined into three new ones; 'Building Communities', 'Impact and Influence' and 'Sustainability' Committee, in addition to the Finance Committee. The aim of this restructuring is to tie into the Microbiology Society's three strategic objectives more closely (for more details of these, visit **microbiologysociety.org/strategy**). While previously the objectives were applicable to several committees and there was a lot of overlap, revamping them this way will hopefully mean we can achieve these objectives in a much smoother way. Additionally, we will now have at least two ECM Forum Executive Committee members on each committee, maintaining an early career voice at Governance level.

The start of the year also saw the publication of a Prince's Trust report on mental health. The report found that one in four young people had been 'unable to cope' during the COVID-19 period. Jonathan Townsend, the UK Chief Executive of the Trust, said, "The pandemic has taken a devastating toll on young people's mental health and wellbeing. The report shows that 50% of 16- to 25-year-olds surveyed said their mental health has worsened since the start of the pandemic, with 56% 'always' or 'often' feeling anxious. These results were reported as "the worst findings in [The Trust's] 12-year history".

While this was not a field-specific study, academia and research fields have historically had a high level of impact on people's mental health, especially for students and other early career individuals. It is more important than ever to look after each other, and if you are feeling like you need help, please try to ask for it. Those around you are almost definitely more understanding and willing to step in than you think.

There are lots of organisations that can help if you need someone to talk to, and a comprehensive list is available on the NHS website (**nhs.uk/conditions/stress-anxiety-depression/mental-health-helplines**). Samaritans is also an amazing charity that provides a free 24-hour helpline where you can speak to fully-trained volunteers who can help you talk through your concerns, worries and troubles. Their number is 116 123.

Finally, I'd like to say thank you to all members who took part in the last ECM Forum Online event and who continue to support and participate in early career activities within the Society. Take care everyone, stay safe and look after yourselves!

Robert Will

Impact and Influence Representative,
ECM Forum Executive Committee

rcw59@cam.ac.uk

Shape the Society's work while gaining committee experience – join the Shadowing Scheme today

Our Council and Committees Shadowing Scheme is a fantastic opportunity to get a look into the inner working of the Society. Many readers will be aware that Committees and Council exist; however, they may not know what they are letting themselves in for when they are nominated for elections.

Tsyhun/Thinkstock

Our Shadowing Scheme is a very low-impact way of finding out more, building a relationship with a current Council or Committee member and essentially 'trying before you buy'. We hope that by understanding the way our decision-making bodies work, more members will put themselves forward to participate in Society activities.

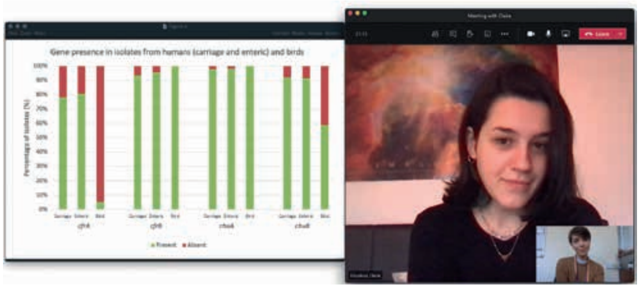
Serving on Committees can bring huge benefits to your career and professional development. From exposing you to a wider range of views to giving you the opportunity to contribute to the shape of the Society's activities and programmes, our Council and Committees are made up of change-making members who are invested in contributing to the microbiology community.

Our website has further details, including the experience of members who have participated in the scheme in the past. Find out more and apply to join todayat **microbiologysociety.org/ShadowingScheme**.

Spotlight on Grants: Harry Smith Vacation Studentships

Harry Smith Vacation Studentships facilitate short research projects for second- or penultimate-year undergraduates during their summer vacation. In turn, the scheme supports budding research scientists and provides opportunities for early career researchers to gain supervision experience.

Last summer, several funded projects were safely adapted to accommodate the ongoing coronavirus pandemic, with some projects incorporating remote working, considering new health and safety regulations or contributing towards SARS-CoV-2- and COVID-19-related research. Here, we catch up with some awardees to find out more about their experiences.



Screenshot of an online Teams meeting between Mariklairi and Natalie. Natalie Barratt

Supervisor: Dr Natalie Barratt
Student: Miss Mariklairi Kiourkou

Last summer, Natalie and Mariklairi transformed their initial lab-based proposal into a remote bioinformatics project with the aim of using the Bacterial Isolate Genome Sequence Database (BIGSdb) to screen samples of *Campylobacter jejuni* and *Campylobacter coli* for the prevalence of various iron-uptake systems. By doing so, they were able to create a genomic scheme to quickly identify iron-uptake systems in pathogenic campylobacters.

Mariklairi said, "This project has been a perfect opportunity for me because I learned the whole process of finding a new project and organising my thoughts on how I must approach a biological matter."

Natalie said, "This has been a great experience in terms of managing a small research project independently. This is the first time I have overseen a bioinformatics project and worked on a project remotely, so that was helpful as this style of teaching and supervising is bound to be more commonly used this academic year in particular."

Supervisor: Professor Fiona Henriquez
Student: Miss Charlotte Tembo

Fiona and Charlotte investigated the efficacy of a new form of face-covering fabric that had the potential to reduce the risk of community transmission of pathogens, including the coronavirus. This was done using a surrogate model of SARS-CoV-2, the murine hepatitis virus (MVH), which was nebulised via a mechanical breathing apparatus before the presence of viral particles were assessed via real-time PCR and median tissue culture infectious dose (TCID50).

Charlotte said, "the highlight of my internship was working alongside professionals in the microbiology field on a project that is COVID-19 related. I really enjoyed being taught and trained by the technicians on how to conduct experiments on my own, as this really increased my confidence working in the laboratory environment whilst developing my skills in cell culture, infectivity assays, microscopy and data interpretation."

Fiona said, "Non-COVID-19-related research was paused during lockdown. At the same time, we got the great news that Charlotte's application to the Harry Smith Vacation Studentship was successful, but alas we could not engage in the original project, as cells were frozen and reagents were prioritised for COVID-19-related research. The opportunity for Charlotte to contribute to our understanding of coronavirus *in vitro* was evident, and we submitted a request to change the aims of the original project. The process was straightforward and complemented the process that would allow student training to occur under strict health and safety regulations and management during the pandemic. It was wonderful to be able to host Charlotte in the laboratory and to witness her integration into the research team. Also, the research team enjoyed being involved in her training and her results helped move the other projects forward."

Charlotte on the last day of her placement, assessing microscopically the health of murine cells she inoculated with MHV in a TCID50 assay to determine whether they had been virally infected. Fawziye Tarhini

Applications for the Harry Smith Vacation Studentship open in December each year. To find out more about the wide range of grants to support Microbiology Society members, visit the grants area of our website (**microbiologysociety.org/grants**).

Open Science: what does it mean to you?

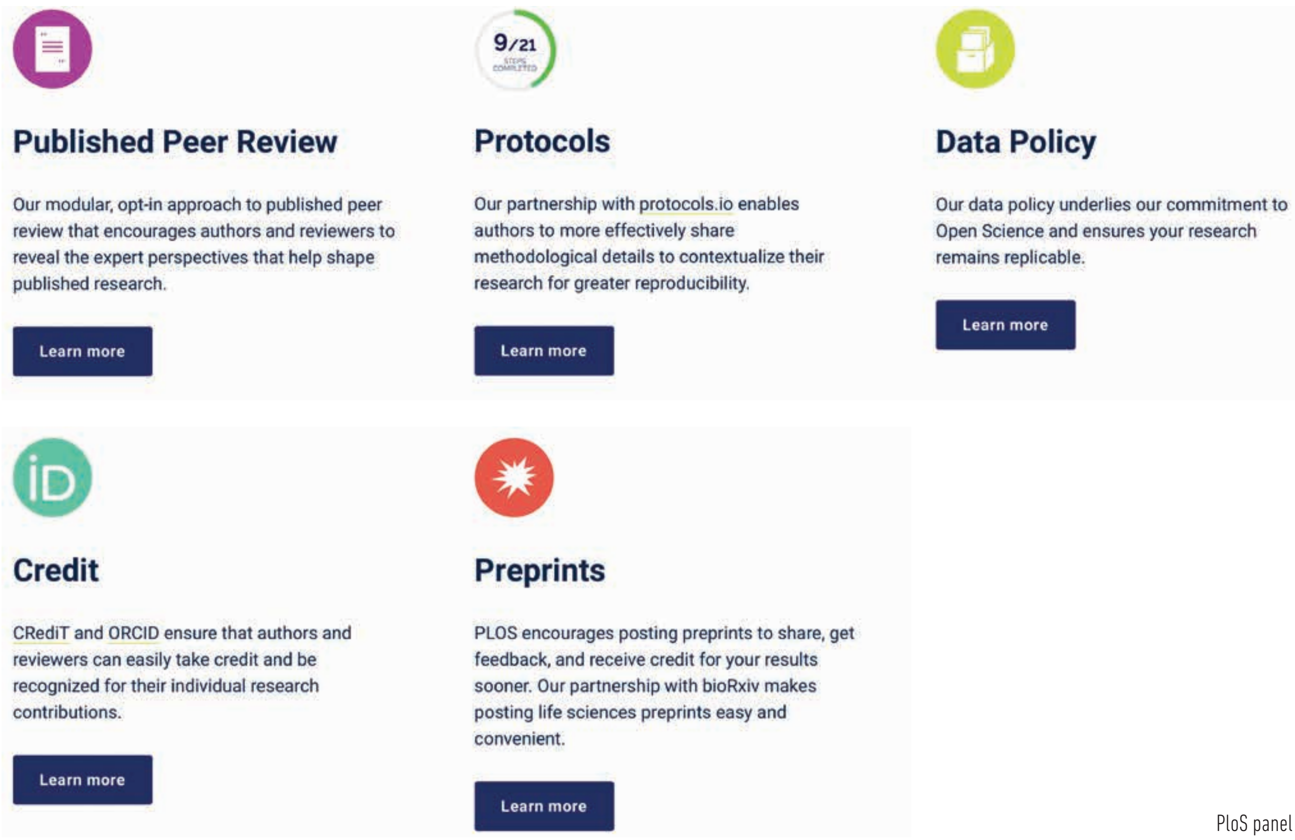
> With time, we have become increasingly familiar with the concept of forced wants and unfamiliar with the concept of basic needs.
>
> *Rajesh, Random Cosmos*

The Society explores Open Science in this opinion piece, with the hope of provoking responses and feedback. Please tell us what you think.

How easy it is to reduce scholarly communication to its basic needs – we want to publish great science in our journals, right? See, easy! Until new imperatives come along, such as the urgency faced by researchers in finding solutions to deal with a pandemic.

Let's test the hypothesis that Open Science is a 'forced want', a concept dreamt up by a) some in distanced ivory towers, b) tech gurus who believe that the open-source software movement can be translated to science and c) funding organisations with financial motives looking to force change.

The widely cited definition of Open Science is from a 2011 Ted Talk in which physicist Michael Nielsen suggests "the idea that scientific knowledge of all kinds should be openly shared as early as it is practical in the discovery process". Since then, Open Science (also synonymous with Open Scholarship and Open Research) has come to be an umbrella term for various 'Open' components, including Open Access (OA), Open Data,



PloS panel

Open Publishing Platforms and Open Education Resources. Institutions use the term to inject ethics and mission statements, such as transparency, integrity and efficiency. Reproducibility, big science datasets and how to reward good science citizenship are more real-life concerns that have a place under this umbrella. Publishing companies (see PloS panel) have their own unique selection of attributes.

With Open Science meaning many things to many people, institutions and stakeholders in the scientific enterprise, does this agenda start to look like a manifesto, which in turn looks like politics entering science? If so, should we resist paying lip service or do we need to start investigating what are the fundamental changes called for by advocates? When it encompasses such a breadth of concerns, what is manageable, what can we tackle and what will become the basic needs of science?

In theory, Open Science may sit in any number of organisational driving seats and from that produce a different outcome. As a policy, it can guide mission; as a technology-driven practice, it can expand research deliverables; as an enterprise requirement (for OA for instance), it can disrupt a flawed business model. Many in academic publishing see these changes gathering pace, so we want to hear how these changes affect you – our members – as individuals and scientists. How important are these principles and do they affect what publishing choices you make? How does your funder, your university or your peers and collaborators' stance on Open Science impact your research choices and what are the difficulties in practice? What are your drivers and blockers to achieving openness in research practice?

We see some great opportunities in pursuing more openness; perhaps even the fast-approaching day when it will be a basic need. The Microbiology Society has embarked on several major initiatives with Open Science intent, such as launching Publish and Read (**microbiologyresearch.org/publish-and-read**) and developing an open research platform. We look for inspiration from you, our members, to determine the pace and steer us in the right direction. Please write and let us know whether and how important any aspect of Open Science is to the way that you work at **journals@microbiologysociety.org**.

Reference

TED. Michael Nielson Open Science now; 2011. ted.com/talks/michael_nielsen_open_science_now [accessed 7 April 2021].

We hope that you're finding these articles useful. If there is a topic you would like us to address, email us at **journals@microbiologysociety.org**.

LoveTheWind/iStock

The role of microbiology in regulating climate and underpinning climate-smart agricultural systems

Soils harbour over a quarter of all life on the planet, including a staggering abundance and diversity of microbial life. These micro-organisms are integral to the health and productivity of our farming systems and carry out a range of essential functions. Amongst the most important of these is that of regulating climate, with soil microbes playing a critical role in both generating and mitigating greenhouse gases (GHGs).

Fiona Brennan and Natalie Oram

Micro-organisms are the engines of nutrient cycles in soils, transforming nutrients from one form to another. These nutrients are the basis of food production, but during these cycles, nutrients can also be lost to the atmosphere as GHGs. Within agricultural soils, the primary GHGs of concern are carbon dioxide (CO_2) and nitrous oxide (N_2O). Soils represent the largest global terrestrial store of carbon (C), holding more C than the atmosphere and plants combined. The net balance of C in and out of soil is therefore crucial to global C cycling. A key focus of international efforts to regulate the climate has been to increase the C sink capacity of soil by enabling conditions where soils sequester more CO_2 than they emit. Fundamental to the success of these efforts is understanding how C is stabilised, with recent evidence suggesting that microbes play a key role by transforming C into more stable forms and that microbial necromass (dead microbial material) may be the most stable component of soil C.

N_2O is a potent GHG with a global warming potential nearly 300 times greater than CO_2. In Ireland, more than 90% of N_2O emissions come from agriculture, largely from microbial transformation of nitrogen (N) in soils by a process known as denitrification. Many soil microbes can transform N in this way and some also have the capacity to mitigate N_2O emissions by transforming it into benign N_2 gas. Whether N_2O is produced or transformed depends on the microbial community composition and environmental conditions. The integral role microbes play in C and N cycles raises the possibility of harnessing knowledge of the soil microbiome to help reduce GHGs in our agricultural systems. As research helps us elucidate the impact of agricultural management (such as liming, crops grown, cultivation methods and fertilisation) on the microbes that orchestrate these processes, there is potential to mitigate GHGs. A further avenue towards reducing GHGs is utilising microbes to facilitate agricultural production in low-input systems that produce fewer emissions.

While microbial processes can contribute to climate change, they are also impacted by the effects of it. Climate change can disrupt the soil microbial communities, affecting how they cycle C and N. Increased frequency and severity of floods and droughts could stress soil microbes to a point where they may not recover from these weather events. How soil microbes respond to such challenges has important consequences for the soil functions we depend on, including food production, C storage and climate regulation. Flood events in grasslands have been found to increase N_2O emissions by orders of magnitude, and droughts can drastically reduce C storage. These events can also disrupt the intimate connection that plants and microbes have, reducing the C exuded via plant roots, the main source of energy for many microbes. This could also affect the benefits that microbes provide to plants: nutrient uptake, growth promotion and stress reduction.

Research has shown that it is possible to mitigate the negative effects of climate change on soil microbes and their functions which we depend on. First and foremost, we need to address the root of the problem, slowing climate warming by significantly reducing our GHG emissions. Secondly, understanding how climate change affects soil microbes and their interactions with plants could allow us to manage our land in a way to create climate-change resilient soils. This is a daunting task, as there is still so much to learn about the soil microbiome, plant–soil interactions and their responses to climate change. What is known is that conserving soil biodiversity is essential to preserving the ecosystem functions that soils provide. We can do this by diversifying the plant species we grow, reducing over fertilisation, preventing soil physical damage and building soil organic matter. For example, growing mixtures of plant species with diverse characteristics in grasslands or building soil organic matter via cover cropping, diverse crop rotations or including crops with deep, fibrous roots in cropping systems. Essentially, preparing a feast of carbon that satisfies a wide variety of microbial tastes can foster a diverse soil microbial community that performs the functions we depend on.

Fiona Brennan

Department of Environment, Soils and Land-Use, Teagasc (Irish Agriculture and Food Development Authority), Ireland

Natalie Oram

Department of Environment, Soils and Land-Use, Teagasc (Irish Agriculture and Food Development Authority), Ireland; and Department of Ecology, University of Innsbruck, Austria

26th UN Climate Change Conference of the Parties (COP26)

This year, the UK will host the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow, on 1–2 November 2021. At the summit, delegates including heads of state, climate experts and negotiators will come together to agree on coordinated action to tackle climate change.

The UK Presidency provides a platform for the UK to take an international leadership role and champion a green recovery from coronavirus which creates sustainable jobs and addresses the global challenges of public health, climate change and biodiversity loss to safeguard the environment for future generations.

Microbiology can play a leading role in tackling climate change, as micro-organisms and microbial processes can be harnessed into nature-based solutions to mitigate the effects of climate change. Ahead of COP26, there is an opportunity for microbiologists to showcase the important role of microbiology in this global challenge and share knowledge with others on the frontline of climate action.

Member Q&A: Stephen Polyak

Stephen Polyak

This is a regular column to introduce our members. In this issue, we're pleased to introduce Stephen Polyak.

Where are you currently based?

Virology Division, Department of Laboratory Medicine and Pathology, University of Washington, Seattle, WA, USA.

What is your area of specialism?

Virology.

And more specifically?

Virus–host interactions, virus-induced inflammation, approved drug repurposing as broad-spectrum antiviral agents. I have worked on hepatitis C virus, HIV, filoviruses (Ebola), arenaviruses (Lassa) and now, SARS-CoV-2.

Tell us about your education to date.

1987, BSc; 1993, PhD: both from McMaster University, Hamilton, ON, Canada.

Where did your interest in microbiology come from?

Grade 10 class on cell biology, followed by 3rd-year molecular biology and 4th-year virology courses during my undergraduate studies at McMaster.

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

As an academic researcher, funding is the main challenge. One way to stay competitive and funded is to be like the RNA viruses I study: adapt to work in new environments, i.e. work on new viruses. Another way is to build international collaborations to open up avenues for funding from different agencies. Persistence is also key, along with the intuition (and luck) to know when to switch tracks.

What is the best part about 'doing science'?

Building collaborations, creating and implementing ideas that never existed before, working with smart and good people to tackle big questions, and developing sustaining relationships with valued, trusted and respected colleagues and friends.

Who is your role model?

I have several. Athletically, Wayne Gretzky, a superstar hockey player from my hometown of Brantford, ON, Canada. Gifted player, who is respected on and off the ice, and most importantly, a team player. Scientifically, my current collaborators and friends, Drs Judith White and Mary Paine. They are rigorous and precise scientists, effective and timely communicators, and wonderful people to work with and know. Musically, Sir Paul McCartney, whose music has been a soundtrack for key parts of my life.

What do you do to relax?

Sports: ice hockey, cycling, hiking, kayaking, Orange Theory (when they reopen!). Arts: play the guitar, write and sing songs, play gigs with Stark Polarris, a band created with University of Leeds Virologist, Professor Mark Harris. Social: talk to my daughters, my wife Suzanne, visit microbreweries and wineries with friends, family and lab members. Pet my cat Eudora.

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

Abbey Road. Continuous, fresh, cold sparkling water.

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

I was once interviewed on TV by hockey legend Bobby Orr.

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

A touring musician.

If you would like to be featured in this section or know someone who may, please get in touch with our Membership team, at **members@microbiologysociety.org**.

Exclusive member resources and opportunities

Society members benefit from numerous opportunities for professional and personal development, as well as the possibility to become more involved with the wider microbiology community and drive collaboration and growth in the field.

Mi Society

The Mi Society platform is an exclusive members' only area designed to offer an overview of the latest updates and opportunities, all available in one place. Make sure to visit the page by logging in to your account and staying informed with the latest initiatives and projects.

Members' Directory

The Members' Directory allows you to find other microbiologists in your field of interest and connect with them. You can update your own details in your profile to ensure fellow scientists can reach you.

Members' resources

We have several resources available for Society members, designed to support personal and professional development and focused on various topics including education, teaching, outreach and more. You can access the resources via our Members' Outreach & Resources section of the website. If you have any suggestions to contribute to our resources area, please get in touch with us at **getinvolved@microbiologysociety.org**.

Champions' Scheme

We are always happy to welcome more members into the Champions community at the Society. The Champions' Scheme allows active members to get more involved with Society activities and put forth their own initiatives with support from the Society. If you are already running engagement activities and are not yet a Champion, the scheme can provide financial and advisory assistance to support your project.

Coccus Pocus 2020: a microbiology-inspired scary story competition about biofilms and antimicrobial resistance

In October 2020, the Department of Biomedical and Forensic Sciences at the University of Hull launched an exciting scary story competition for Halloween, Coccus Pocus 2020!

The competition was supported by the National Biofilms Innovation Centre as part of their #BiofilmAware campaign, which is all about helping people to understand what biofilms are and why biofilms are so important.

Dr Morgan Feeney from the University of Strathclyde, Dr Leena Kerr from Heriot-Watt University, Dr Nadia Andreani from the University of Lincoln and Mr Giridhar Chandrasekharan from the University of Warwick kindly offered to act as Coccus Pocus Ambassadors, communicating the event at their institutions.

Winner of the first prize, Ms Farhana Alam Burnett, University of Birmingham.

The contestants were encouraged to write a short horror sci-fi story between 500 and 2,000 words, including antimicrobial resistance and/or microbial biofilms. The story evaluation committee ranked the stories according to the intrigue of their plot, use of language, character description and scientific soundness.

The first prize (a £100 Amazon voucher) was awarded to Ms Farhana Alam Burnett, a microbiology PhD student from the University of Birmingham. Her thrilling story, *Persisters*, is about a domestic fungal biofilm that does much more than smelling bad!

Ms Amisha Sathi, an undergraduate from the University of Warwick received the second prize (a £30 voucher) for her story *Abnormal*, where the protagonist fights a horde of slimy hostile creatures in a post-apocalyptic horror setting.

Finally, Ms Bethany Pearce, again an undergraduate student from the University of Warwick, was given the third prize (a £20 voucher) for her story *Day 0*, which tells us the tale of a patient suffering from an antibiotic-resistant superbug infection that spreads rapidly all over the hospital.

Coccus Pocus will run again in October 2021. Can you think of any biofilm- or AMR-related scary stories? Would you like to be one of our Coccus Pocus Ambassadors? And… which university or school will claim our next trophy? Read more about the competition and download the winning stories on our website (**microb.io/coccuspocus2020**).

Georgios Efthimiou
University of Hull, UK

Reviews

Read excerpts from the latest book reviews below. To read the full reviews, and for more reviews, please visit our website: **microbiologysociety.org/MTMay2021Reviews**

Leeuwenhoek's Legatees and Beijerinck's Beneficiaries: A History of Medical Virology in The Netherlands

By Gerard van Doornum, Ton van Helvoort and Neeraja Sankaran
Amsterdam University Press (2020)
£39.46 ISBN: 978-9-463720-11-3

This book provides a detailed historical perspective on the development of medical virology in Amsterdam and aims to fill a gap in the history of Dutch virology. The use of references from scientists, articles, journals, books, historical records, conference proceedings, seminars, workshops and many resources during the twentieth century made this book an interesting and engaging read. This book will be a valuable addition to any library and to any bioscience student who is interested in the history of microbiology.

Arindam Mitra
Adamas University, India

Climate Change and Microbial Ecology: Current Research and Future Trends (Second Edition)

Edited by Jërgen Marxsen
Caister Academic Press (2020)
£199 ISBN: 978-1-913652-57-9

Climate Change and Microbial Ecology: Current Research and Future Trends is focused on the understanding of micro-organisms and the contributions and responses they make to their ecosystems. For individuals interested in global climate change and intrigued by microbial ecology and environmental science, this book is heavily descriptive and delivers an informative guide. I have found this book to be very factual, easy to navigate and provides us with a clear insight into emerging bacteria around the world that any level of reader would be able to comprehend.

Bradley Crowson
The Open University, UK

Bacterial Genetics and Genomics

By Lori A.S. Snyder
Taylor & Francis Ltd (2020)
£47.99 ISBN: 978-0-815345-69-5

Bacterial Genetics and Genomics should be praised for the discussion of the ecology and evolution of bacteria and their viruses through the lens of their molecular biology and genome biology, contextualising this with concerning global challenges, as it has reminded me why I love to study bacteria through their genomes. As a basic reference in the undergraduate and postgraduate curriculum, this book will surely help to inspire the next generation of bacteriologists.

Bruno Francesco Rodrigues de Oliveira
Federal University of Rio de Janeiro, Brazil

Veterinary Vaccines: Current Innovations and Future Trends

Edited by Laurel J. Gershwin and Amelia R. Woolums
Caister Academic Press (2020)
£199 ISBN: 978-1-913652-59-3

This book covers a range of vaccine technologies and immunotherapy and has been organised into seven chapters, with each covering a different aspect of veterinary vaccines from cancer through to infectious diseases. By reading this book, a researcher will gain a broad understanding of the background of various vaccine technologies, through to the application of that technology in the veterinary context. However, due to the limited use of relevant illustrations in the various chapters, some concepts may be more difficult to grasp for some readers. Overall, the book is a valuable resource for research students and scientists working on veterinary vaccines.

Thiru Vanniasinkam
Charles Sturt University, Australia

Comment: Wildfires and COVID-19: a planetary health emergency

Rosa von Borries and Rachel Lowe

Wildfire seasons are becoming longer, more intense and more severe, causing devastating environmental and economic damage at a global scale and pushing emergency services to the brink. In 2020, wildfires raged in Western US states, Australia, India, Siberia and Ukraine, including the largest fires ever recorded in California and Colorado. These large-scale wildfires led to record-breaking air pollution levels in several areas. For instance, $PM_{2.5}$ levels ($PM_{2.5}$ [where PM is 'particulate matter'] refers to particles with an aerodynamic diameter less than 2.5 µm) in California reached 453 µg m^{-3} compared with the safe mean annual limit of 10 µg m^{-3}, recommended by the World Health Organization. While trying to keep the unprecedented fires under control, these countries also had to find ways to control the rapid spread of COVID-19. In several wildfire-affected areas such as Brisbane, N95 masks were in short supply, given that masks were required to protect individuals from both wildfire smoke and the novel virus.

Complex interconnections of climate change and wildfires

The year 2020 was one of the three warmest years on record, with the global mean surface temperature measured 1.2 ± 0.1 °C above the pre-industrial baseline, according to the World Meteorological Organization. Climate change is assumed to be a major cause of the increasing likelihood of wildfires, which is driving many forests into drought stress, reducing the vegetation water content. In return, wildfires drive global warming by contributing to increased CO_2 emissions, resulting in a vicious cycle of global environmental change and enhanced wildfire risk. Besides causing profound environmental destruction, the impact of wildfire smoke on human health and potential synergistic health effects with COVID-19 are expected to be huge.

Influence of wildfire smoke on the human respiratory system

Wildfire smoke is a complex mixture of small particles and gases which varies depending on the weather, burning material, fire temperature and distance of smoke dispersion. Wildfire smoke components include $PM_{2.5}$, volatile organic compounds (VOCs), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and ozone (O_3). Among these, $PM_{2.5}$ poses the highest risk to human health as it can penetrate deeply into the lungs due to its small particle size, causing oxidative stress and inflammatory responses. Wildfire smoke exposure can lead to increased exacerbations of asthma or chronic obstructive pulmonary disease (COPD) and a decrease in lung function. Asthma-related hospital admissions were found to increase by 6% for each 10 µg m^{-3} increase in $PM_{2.5}$ from wildfire smoke, indicating that wildfire-associated $PM_{2.5}$ might cause stronger negative health effects than $PM_{2.5}$ from other sources.

Impact of fine particulate matter on COVID-19 mortality

Since the emergence of SARS-CoV-2, researchers have been concerned with identifying key environmental factors potentially driving COVID-19 dynamics. The current state of knowledge indicates a positive relationship between acute and chronic air pollution exposure and COVID-19 severity and mortality. Air quality factors can affect COVID-19 outcomes by compromising the immune system, e.g. causing an overexpression of cytokines and chemokines. A second potential mechanism occurs via aerosol dynamics of virus transmission as $PM_{2.5}$ might represent a potential transport medium for SARS-CoV-2, enhancing virus survival and diffusion of virus particles. Long-term exposure to air pollution in the US was shown to be associated with an 11% increase in mortality from COVID-19 infection for every 1 µg m^{-3} increase in air pollution. Long-term exposure to particulate matter was further estimated to contribute to approximately 15% of COVID-19 mortality worldwide. These findings emphasise the potential role of fine particulate matter in modifying COVID-19 mortality risks, indicating the critical need to monitor air pollution levels and issue warnings and recommendations when $PM_{2.5}$ levels exceed dangerous limits.

Compound effects of COVID-19 and wildfires on human health

$PM_{2.5}$ from wildfire smoke can compromise the immune system and contribute to increased respiratory symptoms,

Forest Fire in Dixie National Forest, Utah, USA. santirf/iStock

which in turn increase the risk of COVID-19 complications. Wildfire smoke exposure might also increase the likelihood of comorbidities, including cardiovascular diseases, respiratory diseases, diabetes and hypertension, leading to an increased COVID-19 risk. Higher daily average $PM_{2.5}$ concentrations during the wildfire season in western US states were positively associated with increased influenza rates the following winter, indicating strong evidence for delayed effects of wildfire exposure. Research on understanding the underlying mechanisms between wildfire exposure and respiratory infection is an area of active investigation.

In particular, vulnerable population groups such as socio-economically disadvantaged populations, individuals with comorbidities and the elderly face higher risks of experiencing the combined consequences of COVID-19 and wildfires. In the US, migrant farmworkers who were continuously exposed to wildfire smoke and deemed essential workers during the pandemic faced much higher risks of severe health consequences from wildfire smoke and COVID-19. The combined impact of wildfire smoke and COVID-19 needs more attention to effectively adjust mitigation strategies to protect the most vulnerable, especially in regions with high levels of wildfire-associated air pollution.

Further reading

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