CLIMATE CHANGE:
MICROBES AS OUR ALLIES

Climate Change: Microbes as our Allies

> Microbes' pervasiveness and sheer abundance on our planet hints at a global-scale role and impact that we have only started to understand. From new species to new bioproducts, results from fundamental and applied microbiology are increasingly revealing microbes as a potential source of new solutions to heal the world
> Professor André Antunes

Key Points

- Microbes play key roles in biological systems, contribute to our changing environment and are intricately linked with climate change. They exist in our oceans, deep in the soil and as high up as the stratosphere, yet less than 1% have been discovered and their extensive influence on our planet is therefore largely unexplored.

- Like all living things, microbes are affected by and struggling to cope with the devastating consequences of climate change such as ocean acidification, soil warming and melting of permafrost. Rapidly changing environments have critically jeopardised their ability to survive and are shifting the composition of microbial communities.

- We can harness the capabilities of microbes to combat climate change. By employing microbes, we can reduce greenhouse gas emissions and transform how we manage waste, produce crops and generate electricity to limit our impact on the environment.

Climate change is a planetary threat that will devastate communities and environments across the globe if left to its own devices. The COVID-19 pandemic has demonstrated that, by bridging the gap between science and policy, we can rise to global challenges. We should take these strategies forward with a similar urgency in our fight against climate change. Micro-organisms infiltrate every corner of the built and natural worlds, and microbiology research deepens our understanding of the challenges we face and aids the development of policies to combat and cope with the consequences of climate change.

Why are microbes important for climate change?

Despite their tiny size, microbes play key roles in almost all systems because of their ubiquitous nature. They are responsible for both the production and consumption of greenhouse gases and are thereby inextricably linked with climate change.

Marine microbes

The global ocean covers more than 70% of the Earth's surface and is remarkably heterogeneous. Marine productive areas and coastal ecosystems comprise a minor fraction of the ocean in terms of surface area but have an enormous impact on global biogeochemical cycles carried out by microbial communities, which represent 90% of the ocean's biomass. For instance, marine phytoplankton carry out 50% of global photosynthetic CO_2 fixation [1,2]. There are more bacteria in our oceans than stars in the universe, yet we have only been able to study less than 1% of the total bacterial species. This means that the true impact and capabilities of marine microbes are likely to be far greater than what the current estimates suggest.

Atmospheric microbes

Microbes exist in the clouds, the ozone layer and as high up as the stratosphere. By analysing the diversity of life at such high altitudes, we can better understand the implications of atmospheric microbial activity for greenhouse warming and weather systems. Human activity such as rocketry, military activity and air pollution all contribute to changes in atmospheric microbial composition. Atmospheric microbes can induce cloud formation and precipitation, and as many as ~1 million tons/year of organic carbon is metabolised by bacteria in the clouds [3]. Study of these complex dynamics is necessary to understand the extent of their contribution to climate change and the depletion of the ozone layer. Significant progress has been made in recent years to characterise atmospheric biological material. However, atmospheric life is sparse and difficult to capture, so the degree to which micro-organisms are affected by or contributing to climate change is largely unknown.

Soil microbes

The soil microbiome[1] is extremely complex and diverse, and soil microbial communities are instrumental in the control of greenhouse gases – they release CO_2 by mineralising soil carbon and absorb CO_2 by stabilising atmospheric carbon, the balance between these processes determine whether soils act as a carbon source or a carbon sink. Soil is directly affected by almost all effects of climate change, such as increased temperatures, droughts and floods. Therefore, it remains difficult to predict whether soil will become a future carbon source or sink. One major concern is that globally soil micro-organisms will mineralise more carbon than they absorb, which will contribute significantly to greenhouse gas emissions [4]. Furthering our understanding of the soil microbial ecology that controls this balance is a pressing need for predicting future change.

How is climate change disrupting microbiomes?

Ocean acidification

Ocean acidification (OA) is the ongoing decrease in the pH value of the Earth's oceans, caused by the uptake of CO_2 from the atmosphere. The main causes of OA are human activities, namely the burning of fossil fuels. As a consequence of OA, marine micro-organisms are presented with pH conditions well outside their internal range, leading to a disruption of cell functions and key biological processes (such as organism physiology and population dynamics), which in turn alters community structure and throws fragile ecosystems out of balance. OA also causes changes in carbon cycling and cellular growth, causing disruptions in the food chains [5]

[1]A microbiome is a community of micro-organisms that inhabit a particular environment.

Bacterial blooms

Bloom forming bacteria grow in the ocean and produce toxins that threaten the survival of wildlife and risk contaminating our water supply. Climate change favours the survival of toxic cyanobacteria that thrive at high temperatures, meaning that instances of toxic blooms are likely to become more frequent [6].

Soil warming

Climate change directly affects soil microbe composition, altering temperature and moisture content. Higher temperatures will increase the rate at which soil micro-organisms grow and respire, leading to an increase in CO_2 release [7].

Permafrost melting

Polar and subpolar regions are disproportionately affected by climate change and warm significantly faster than the rest of the planet. Warming-induced thawing of permafrost activates microbes, stimulating the breakdown and decomposition of organic carbon. This releases CO_2, leading to further warming and triggering a positive feedback system. At the University of Leeds, researchers have used a computational method called 'oligotyping' to analyse the diversity and distribution of microbes on the Greenland Ice Sheet [8]. Their work will serve to further the understanding of microbiome-induced melting and inform predictions for future melt rates.

Diseases

Climate change exacerbates the impact of pathogenic diseases (e.g., Lyme disease and West Nile virus), which has consequences not only for human health, but also for aqua- and agriculture, threatening global food supply. Microbiologists are working to monitor the enhanced spread of pathogens in response to global warming, including *Vibrio harveyi* [9], a causative agent of fish diseases, seafood spoilage and various fungal phytopathogens that affect crops and food security. Population growth and travel combined with climate change have also promoted antibiotic resistance and the global spread of pathogens that infect humans. A recent study found that, while increased temperatures did slow the expansion of COVID-19, this cannot necessarily be translated to mitigation of future pandemics. More research to determine the complex dynamics at play [10].

Box 1. Good COP, Bad COP

In October 2021, the COP26 summit brought parties together to accelerate action towards the goals of the Paris Agreement and the UN Framework Convention on Climate Change. $130 trillion were pledged towards achieving net-zero greenhouse gas emissions, with countries and private organisations committed to greater transparency with regards to the measurement of progress. However, the parties failed to meet the Paris Agreement target of limiting the global temperature rise to 1.5°C above pre-industrial levels by the end of the century, and to secure the $100 billion per year promised in climate finance at COP15.

How can microbes be used to combat climate change?

Waste management

Approximately a third of food produced for human consumption is wasted globally, and 47% of this waste is generated before the food enters supermarkets. At the University of Nottingham, researchers are exploring the use of electrolysed water to sanitise fruit and vegetables to reduce contamination of foodstuffs [11]. At the University of Malta, a team is assessing the effectiveness of hyperspectral imaging – a low-cost, non-destructive food inspection technique for identifying microbial contamination [12]. Deployment of these techniques at critical points during food production can significantly reduce food wastage.

Another alternative to dealing with food waste is to convert it into useful products. Food waste is naturally converted into volatile fatty acids and by-products like nitrogen and phosphorus. Micro-organisms can use these to produce bio-alternatives to petroleum-based plastics. In a promising breakthrough, an EU Horizon 2020 project found that plastic can be upcycled into a novel bio-based polymer known as bio-PU. Microbiologists have collaborated to engineer a bacterium capable of carrying out this process which will contribute to the transition to a circular economy and reduce the use of petroleum [13].

Bioremediation

Microbes can help clean up soil and groundwater by degrading pollutants through a process known as bioremediation, which converts harmful chemicals to a less toxic state. Showcasing the potential wider reach of such capabilities, the University of Sheffield Source Area BioREmediation (SABRE) project considers how micro-organisms can biodegrade contamination from carcinogenic sources to reduce the negative impacts of carcinogenic contamination [14].

The UK is one of the largest producers of electronic waste (e-waste), which includes anything with plugs, chords and electronic components. Most e-waste ends up in landfills, releasing toxic chemicals like lead and mercury into surrounding soil and water. Microbiologists around the world are working to characterise the microbial species that can contribute to the safe disposal of e-waste through bioremediation. Microbial processes can also be harnessed in the recovery of precious metals. Bacteria that can survive under extreme pH conditions are able to oxidise e-waste and contribute to metal extraction in a process known as urban biomining [15].

Even as we transition away from fossil fuels, oil pollution will persist in the environment. Hydrocarbon-degrading microbes thrive in oil-contaminated sites and can biodegrade oil compounds. Microbiologists are working to enhance this process through the addition of slow-release fertiliser that incorporates nutrients into the oil-polluted sites [16,17].

Exoelectrogens are a useful type of micro-organism for the bioremediation of wastewater contaminants like phenol and uranium [18]. Exoelectrogens can also transfer electrons extracellularly and, in the future, this bacterial flow could be exploited to generate electricity using microbial fuel cells (MFCs).

Agriculture

Microbiologists are working to increase sustainability and mitigate climate impacts of modern agricultural practices using Climate-Smart Agriculture (CSA). The benefit of micro-organisms can be maximised using CSA practices like crop rotation, fungal inoculation and the addition of probiotics to stimulate the growth of beneficial bacteria, such as rhizobacteria. A 2017 study found that the application of rhizobacteria improved root growth and increased the resilience of wheat to environmental stress [19].

Mycorrhizal fungi (MF) are also important for agriculture and form symbiotic associations with most land plants. While plants can extract carbon from the air via photosynthesis, they are not particularly good at mining the soil for nutrients; and while MF can grow to access phosphate in far-reaching corners of the soil, they are unable to photosynthesize. Through their association, plants and MF can trade resources between each other. Research into this relationship has important implications for food security, biodiversity and sustainable agriculture [20]

Renewable energy

Microbiologists investigating fossil fuel alternatives are exploring the development of economically efficient 'biorefineries' – processing systems in which biofuels and other chemical commodities are produced from waste plant feedstock. Using this renewable organic material as an alternative energy source will reduce greenhouse gas emissions and contribute to the decarbonisation of energy systems.

Bioethanol is the most prominent liquid biofuel in production today. Produced by the fermentation of plant sugars, bioethanol is completely renewable since the CO_2 released in its combustion is reabsorbed by photosynthesis. Microbes can produce bioethanol from biomass through enzymatic digestion. Researchers at the Centre for Novel Agricultural Products, University of York, are working to identify the responsible enzymes to maximise biorefinery yields [21].
There is an increasing focus on generating biofuel with waste products in countries most vulnerable to the effects of climate change. For instance, researchers at the University of Manchester are working to create a processing plant in the Philippines which uses rice straw as feedstock, 550 million tonnes of which is burnt per year. Researchers are also working in Vietnam, Colombia and sub-Saharan Africa to utilise coffee husks and sugar cane waste in bioenergy production [22].

Reducing emissions

We can complement efforts to curb greenhouse gas emissions with mechanisms that capture CO_2 by using microbes that can convert it into high-value bioproducts such as carbonate biominerals and bio-cements. This could have a significant impact as the production of concrete is one of the major contributors to CO_2 emissions. Methane is another destructive greenhouse gas linked to agriculture. In fact, as much as 40% of the 7 gigatonnes of greenhouse gases produced by 1.5 billion cattle annually come in the form of methane. Microbiologists are working to further our understanding of microbial metabolism and devise strategies to control this issue, for instance through using probiotics and supplements to alter the gut microbiome and reduce methanogenesis [23].

Box 2. UK Climate Policy

The UK has adopted an emissions reduction target of at least 68% below 1990 levels by 2030. However, the viability of this target has been brought into question, with the Climate Action Tracker showing emissions projections under current policies to reduce by just 54–56%. The 'Net-Zero Strategy: Build Back Greener' sets out ambitious goals for reaching climate targets – pledging to support agricultural innovation, dedicate millions to invest in greenhouse gas removal and consider optimal policy approaches to minimise emissions.

Conclusion

Microbiology research is a key contributor to both the monitoring and the mitigation of climate change. Despite important advances in the field of microbiology, most of the microscopic universe remains unstudied. This means that there is an unfathomable number of uncharted micro-organisms that we are yet to identify and that have the potential to help us avoid a climate catastrophe.

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Thanks are due to the following experts for their advice: André Antunes (Macau University of Science and Technology, Macau), Afolake Olanbiwoninu (Ajayi Crowther University, Nigeria).

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Issue date: February 2022

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