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# Resetting urban human-microbial relations in pandemic times

**Cecily Jane Maller**

Centre for Urban Research, School of Global, Urban and Social Studies, RMIT University, Melbourne, Victoria, Australia

**Correspondence**
Cecily Jane Maller, Centre for Urban Research, School of Global, Urban and Social Studies, RMIT University, Building 8, Level 10, Room 13, 124 Latrobe Street, Melbourne, VIC 3000, Australia.
Email: cecily.maller@rmit.edu.au

## Abstract

Microbes, particularly of the viral kind, are currently preoccupying human activity and concerns due to the COVID-19 pandemic. Although for a long time there has been fear associated with 'germs', notably viruses and bacteria and the diseases they cause, the pandemic has set these fears into overdrive. As serious as this ongoing event is, there are broader interests and important alternative narratives about the microbial world permeating current thinking, based on research that intersects with and includes biopolitical and relational research in geography. In an attempt at balancing the prevailingly negative discourses about microbes and the potential harms they can cause, and to encourage more geographers to contribute to understanding human-microbial relations, this paper draws together recent research across disciplines to discuss the prevalence and role of microbes in environments and in and on human bodies. Drawing on ideas of more-than-human care, the paper shows how geographers and other social scientists can and are already helping reset human-microbial relations, and where further work can productively be done.

**KEYWORDS**
antimicrobial, care, environmental microbiomes, human bodies, human health and wellbeing, Indigenous ontologies, microbes, more-than-human thinking

## 1 | INTRODUCTION

Perhaps now more than ever, microbes are front and centre in human consciousness. Almost every aspect of our lived experience is changing dramatically as we seek to render the uncontrollable, controllable through rapidly changing practices of health, hygiene, working, studying, travelling and relating to others (Biedermann, 2020; Caroppo et al., 2021; Kramer & Kramer, 2020). First seen under microscopes by English and Dutch scientists, Robert Hooke and Antoni van Leeuwenhoek, in the 17th Century (Gest, 2004), microbes are microscopic organisms that include bacteria, fungi, viruses and single-celled creatures such as protozoa (Ishaq et al., 2019). Although antibiotics to treat bacterial infections are commonly thought to have been invented in the early 20$^{th}$ Century, evidence shows that for millennia humans have treated bacterial infections using treatments from soil and plants (Aminov, 2010).

Viruses are the smallest microbe and because they cannot multiply without the cells of other living organisms, they are essentially considered a microbial parasite (Villarreal, 2004). Since early 2020, the world has been grappling with the COVID-19 pandemic caused by the novel coronavirus SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2), such that 'we [have] become increasingly alert to ways in which invisible entities' enter human bodies and causing damage to organs, immune systems and lives (Biedermann, 2020, p. 1). Aside from the immunologists and other scientists seeking to understand COVID-19 and end the pandemic, the worlds humans share with viruses and other microbes were already receiving increased attention in diverse disciplines, including biology (e.g., Davenport et al., 2017), ecology (e.g., Mills et al., 2017), built environment studies (e.g., Adams et al., 2016), public health (e.g., O'Doherty et al., 2016), and geography (Beck, 2021; Greenhough, 2012; Hird, 2009; Lorimer, 2020; Maller, 2018). This increasing interest is reflected in other recent 'turns' in the social sciences, including in new materialisms and more-than-human theories (e.g., Bennett, 2010; Coole & Frost, 2010; Haraway, 2008; Maller, 2018), which draw uncritically from Indigenous ontologies (Porter et al., 2020).

Before the coronavirus pandemic hit, the level of scholarly interest in microbes across disciplines is partly due to the expansion of research into microbiomes. 'Microbiome' refers to the community of micro-organisms and their genetic material found in any given environment (Robinson & Jorgensen, 2020), whether in soil, on animal bodies, or inside the human gut. One of the most well-known studies is the Human Microbiome Project (Turnbaugh et al., 2007). Following work mapping the human genome, this project aimed to understand the millions of microbiota contributing to and constituting human bodies and the role they play in evolution (Turnbaugh et al., 2007). Rather than simply a collection of microbes that happen to co-occur, microbiomes are relational; that is, they refer to the relationships microbes have with each other, with macro species, and with their environments, whether that be in the soil or on a human body.

An unavoidable fact from microbiomic studies is that we now know microbes inhabit and are vital to every habitat, and are essential to most organisms. Yong (2016, p. 53) summarises key conclusions, noting 'it is now clear that many animals, from fish to mice, grow up under the influence of bacterial partners.' The findings of research into microbiomes, microorganisms and their multi-species relationships, regularly feature in the media. Although articles often concern gut microbiota and their human health impacts (e.g., Seal, 2021), other innovations are gaining attention. These include stories about fueling microbes with solar power and carbon dioxide to produce food (Carrington, 2021), microbes inhabiting (Amaral-Zettler et al., 2013) and eating plastic (Carpenter, 2021), and microbes that can potentially cure disease (Zimmer, 2018) through measures such as faecal transplants (Shepherd, 2022) and microscopic projectiles that target cancer using magnets constructed by soil bacteria (McKie, 2022). Partially explaining this phenomenon, Yong (2016, p. 249) observes, 'only recently have [microbes] migrated from the neglected fringes of biology to its spotlight-hogging centre.' In short, these developments are changing our view of microbes such that we are better understanding their potential harms, such as from viruses, but also the myriad benefits, omnipresence, and the fundamental reliance all life has upon them. What has also become abundantly clear is that despite prevailing fears, only a very small number of microbes are harmful to people (Greenhough et al., 2018; Yong, 2016). In fact, human pathogens including viruses amount to less than 1% of all microbial species (Editorial, 2011). Particularly pertinent to pandemics, Lorimer (2017, p. 553) argues, 'no microbe is essentially pathogenic; pathogenesis is the outcome of political and ecological relations'.

This rising 'microbial' (Greenhough et al., 2020) or 'probiotic' turn (Lorimer, 2019, 2020) enables thinking about microbes in numerous ways of further interest to geographers. The contributions geographers have already made to this topic include: understanding the mobilities, networks, borderlands and materialities of pathogens (Ali & Keil, 2007; Greenhough, 2012; Hinchliffe et al., 2013; Lorimer, 2017); showcasing human-microbial relations of the gut (Beck, 2021; Lorimer, 2016) and soil (Krzywoszynska, 2019); revealing domestic microbiomes and their multispecies relations in kitchens (Greenhough et al., 2018) and elsewhere in homes (Wakefield-Rann et al., 2018, 2020); and the biopolitics of multispecies encounters in an era of widespread climatic change (Clark & Hird, 2018). As well as temporal and spatial understandings that geographers are so well-placed to address, much of what is compelling about microbes is relational and political; in other words the 'microbiopolitics' (Paxson, 2008).

With the COVID-19 pandemic bringing all microbes and their relations to humans and other species into sharper focus, particularly in urban settings, there is a need and an opportunity for geographers and other social scientists to contribute further to growing scholarship and practice (see also Greenhough et al., 2020). This paper aims to briefly review current research on microbiomes from a range of disciplines to encourage further active engagement with microbial ecologies, relations and their microbiopolitics. I focus the discussion on urban human-microbial relations and microbiomes because most people now live in urban environments (United Nations General Assembly, 2016). Before COVID-19, the health and wellbeing of people living in cities was evident in multiple urban policy agendas, including the UN's New Urban Agenda (United Nations General Assembly, 2016). Relatedly, research and policy-making on urban greening and nature in cities has exploded, including on microbes (Flies et al., 2017; Robinson et al., 2020). In the sections that follow, there is an unashamedly affirmative lens given to human-microbial relations (Hinchliffe et al., 2013) that reflects this work and serves as a juxtaposition to the pervasive antimicrobial view that is only likely to be further entrenched by the COVID-19 pandemic.

Microbiomes are relational, multiple and complex. Their boundaries are ill-defined and permeable and when they are determined, they are arguably artificial if one takes a purely relational perspective (Hinchliffe et al., 2013). Yet boundaries and limits are at times factual and necessary, whilst also largely being unavoidable, in research and the production of knowledge. Acknowledging the potentially false separation, I have chosen two broad groupings of microbiomes to structure the main parts of this paper: environmental microbiomes, including in indoor and outdoor environments, and the microbiomes of human bodies. These two broad settings also work to focus attention on human-microbial relations from an urban, spatial, material perspective for the reasons provided above. The third section draws on ideas of more-than-human care to show how human-microbial relations can be further assisted in moving beyond their largely negative reputations. The final section concludes the paper, suggesting future directions for social and other geographic research.

## 2 | ENVIRONMENTAL MICROBIOMES

This section concerns environmental microbiomes that generally occur as part of urban environments; in other words, microbes and their communities found in outdoor and indoor settings in cities. However, it is important to recognise that microbial communities don't adhere to spatial and temporal boundaries with mobilities and exchanges occurring between rural and urban environments (Douglas, 2008; Spotswood et al., 2021), outdoor and indoor environments, and inside and outside bodies (Robinson et al., 2020), among other boundary-crossings (Hinchliffe et al., 2013).

In the literature, environmental microbiomes are divided into zones with different microbial communities found in soil, on vegetation, in the air (the 'aerobiome') (Robinson et al., 2020), in fresh and salt water, and in and on buildings and their surfaces and contents (Leung & Lee, 2016; Wakefield-Rann, 2021). One of the easiest environmental microbiomes to contemplate is the soil microbiome with its granular materiality making it more readily 'visible'. But there is, of course, much more to soil that is not so readily visible; as Puig de la Bellacasa writes, 'a billion bacteria, thousands of fungi, protozoa and nematodes live in a teaspoon of rich soil' (2019, p. 394). As well as this, urban soils can be laced with 'rubbish, decay [and]… toxic residues' (Robertson, 2020, p. 319). Chemicals interact with microbes, subsequently changing the composition of microbial communities (Wakefield-Rann et al., 2018), in turn changing soil acidity (Douglas, 2008). Environmental microbiomes also interact with and influence one another over different strata. For example, vegetation and soil contribute to airborne microbiota (Robinson et al., 2020).

In ecology, high levels of biodiversity indicate resilient ecosystems and are important for the long-term survival and adaptability of species and ecological communities. Biodiversity is literally a life-support system comprised of diverse genetic resources and relationships (Douglas, 2008; Robinson & Jorgensen, 2020). Like all ecosystems, biodiversity is equally important for microbiomes, whether in the environment or in or on human bodies; the more diverse they are, the more resilient and adaptive they are to shocks and threats (Douglas, 2008; Robinson & Jorgensen, 2020), including to viruses and other pathogens.

The 'biodiversity hypothesis' proposes that the low microbial diversity of urban settings has poor outcomes for human health due to an absence of certain microbes (Flies et al., 2017; Mills et al., 2017) (see also the following section). In response, Mills et al. (2017, p. 2) have proposed the 'microbiome rewilding hypothesis' that contends increasing biodiversity in urban greenspaces 'can rewild the environmental microbiome to a state that benefits human health by primary prevention'. 'Rewilding'[1] in this context, as defined by Western scientists, refers to increasing the biodiversity of microbes in urban environments to reverse the negative impacts urbanisation has had on underlying ecosystems. Robinson et al. (2020)) and Flies et al. (2017) explain that, despite a need for further research, microbiomes should be considered a part of health promoting, biodiverse green infrastructure to increase the diversity of human microbiomes, which in the long term can suppress inflammation and reduce chronic disease. This research puts a different spin on ideas about the benefits of contact with nature (Myers, 2019), and leads to questions of the temporal, spatial, political, affective, and material nature of environments that geographers are familiar with.

Just as there are microbiomes outdoors, there are microbiomes indoors. Microbes inside and on buildings are associated with flows of air, water, food, surfaces, dust, artefacts, clothes, technologies, chemicals, plants, and human and other animal bodies (Meadow et al., 2015; Wakefield-Rann et al., 2018). Indoor microbiomes are primarily influenced by outdoor microbiomes and those on human bodies, mediated by building design, ventilation, occupancy levels and activities (Leung & Lee, 2016). Aside from microbes transferred to interior surfaces by touch and movement, human bioaerosols (airborne biological particles including bacteria and bacteria-laden particles) are considered a major contributor to indoor microbiomes (Meadow et al., 2015). New research is showing that people occupying indoor spaces emit distinguishable personal microbial clouds (Meadow et al., 2015), with estimates of particles emitted of $10^6$/hour (You et al., 2013). Yong (2016, p. 251) explains, 'every time we talk, talk, scratch, shuffle or sneeze we cast a personalised cloud of microbes into space', meaning 'that our microbiome isn't' confined to our bodies. It perpetually reaches out into our environment.' As well humans transferring and aerosolising microbes indoors, studies show indoor airborne microbes reciprocate by contributing to our nasal, oral, and skin microbiomes (Robinson et al., 2020). Rooms with different uses and users are also being found to have different microbial ecologies that are linked to different parts of human skin, gut and oral microbiomes (Leung & Lee, 2016).

There are two main ways the composition of indoor microbiomes is actively mediated: (1) through ventilation and filtering of air flows, and (2) the use of chemicals and cleaning products on surfaces. With the rise of urbanisation, considerable effort has sought to maintain comfortable, controllable indoor air temperatures and movement of air through energy efficiency measures such as draught-proofing (McLauchlan et al., 2017; Wakefield-Rann et al., 2018), passive heating and cooling (Sarihi et al., 2021), and air conditioning (Winter 2013). Different temperatures and ventilation modes change the characteristics and composition of indoor microbiomes, with naturally ventilated rooms having more in common with outdoor aerobiomes than mechanically ventilated rooms (Leung & Lee, 2016). As well as bringing in microbes from outdoors, ventilation practices can also flush out chemicals such as volatile organic compounds, which in turn can also shape microbial ecologies (Wakefield-Rann et al., 2018, 2020). Meanwhile, draught-proofing and other sustainability initiatives have meant new and retrofitted buildings have become highly sealed, limiting the transfer of microbially diverse, 'clean' air from outside to inside as an unintended consequence.

Most efforts in manipulating indoor microbial communities through surface cleaning are focused on elimination. Blanket 'kill' strategies aim to eradicate every single microbe, whether potentially beneficial or harmful. This reduces microbial diversity and changes microbial ecologies when sterilised surfaces are colonised by whichever microbes happen to be in the vicinity (Yong, 2016). The pervasive germ phobia that characterises modernity has been described as an 'antibiotic, antimicrobial worldview' or an 'antibiosis discourse' (Greenhough et al., 2018, p. 2) that is harmful not only to humans (Doron & Broom, 2019), but to the world's ecosystems and other species (Lorimer, 2020) through the overuse of chemicals and the production and consumption of cleaning products. Aside from reducing exposure to diverse microbiomes, any chemicals used in cleaning interact with microbes in ways that are not well understood (Wakefield-Rann et al., 2018, 2020). The same applies to chemicals used in the manufacture of indoor furniture and furnishings which also interact with microbes and change indoor microbiomes (Wakefield-Rann et al., 2018). The proliferation of built structures and technologies via urbanisation, the production and expanding use of chemicals in workplaces and homes, and globally connected and changing practices of everyday life, are essentially creating myriad, novel ecosystems at the microbial level (Broom et al., 2021; Douglas, 2008; Lorimer, 2017; Wakefield-Rann et al., 2018). The cumulative impacts on human health and the broader ecological implications are currently unknown and are probably unknowable. What is known, is that these microbial communities are nothing like those humans have evolved with (discussed further in the following section). However, research shows some of the ways urbanisation changes microbiomes and can enhance the spread of pathogens is through 'antimicrobial resistance, land-use change and overcrowded populations' (Robinson & Jorgensen, 2020, p. 340).

Inside buildings, typically, the idea has been to keep microbes out (Yong, 2016). Yet the COVID-19 pandemic is forcing a rethink of how we live, study and work, focusing on occupancy densities and building ventilation, with higher air circulation rates likely to be implemented in future policies and building designs. Although the concept is to reduce the concentration of pathogens in indoor air, as a corollary, increasing flows of outside air will also bring in diverse, outdoor microbes that result in higher microbial diversity in and on human bodies, enhancing resilience to disease. As Yong (2016, p. 258) writes, 'rather than trying to exclude microbes from our buildings and public spaces, perhaps it is time to lay the welcome mat out for them.' He reiterates that architectural design choices affect the microbial communities of buildings, 'which could then affect the microbial ecology of us' (Yong, 2016, p. 258), in either a positive or negative way, remembering Lorimer's point that no microbe is essentially pathogenic (Lorimer, 2017, p. 544). It seems sensible then to extend the microbiome 'rewilding' hypothesis posited for outdoor environments by Mills et al. (2017), to the 'rewilding' of buildings and indoor environments. This is already happening, by default in some ways, with the rising popularity of green walls, roofs and other vegetated infrastructure of the built environment (Coutts & Hahn, 2015; Loder, 2014); however, the changes to indoor microbiomes, and subsequently human microbiomes and the impacts on physical and mental health, is yet to be understood. What is probable, however, is that when indoors, people are more likely to be experiencing impoverished environmental microbiomes, or alternatively, those with novel ecologies. The next section takes a closer look at the microbiomes associated with human bodies and their impacts on health and wellbeing.

## 3 | THE MICROBIOMES OF HUMAN BODIES

Scholars as diverse as Yong (2016), Bennett (2010), Mol (2002), Hird (2009) and Haraway (2008, 2016) assert that humans are, literally, never just one body. Microbiology supports these assertions; there are ten times more microorganisms in an average human body than there are human cells (Lorimer, 2016; Turnbaugh et al., 2007; Yong, 2016). Human bodies are essentially immersed in and comprised of microbes that become part of who we are, including in our eyes, noses and guts (Robinson et al., 2020; Turnbaugh et al., 2007). In fact, humans have different microbiomes on different parts and sites of our bodies; so the microbiota on each hand, on our faces, and in mouths or guts are different and they change as our bodies grow and age (Huang et al., 2020). Microbes perform or support a range of 'obscenely complicated' bodily functions including, 'replenishing the linings of the gut and skin, replacing damaged and dying cells with new ones', maintaining the blood-brain barrier, and training and driving our immune system (Yong, 2016, p. 63). They also produce vitamins we do not have the genes to make, break down food in the gut to extract nutrients, and teach immune systems how to recognise invaders (Yong, 2016). In other roles, microbiota regulate drug metabolism and may even influence risk taking and psychomotor skills (Flegr, 2007). Relatedly, the brain-body system and neurological health is also increasingly understood to be supported by microbes, based on connections between environmental and human microbiomes (Leung & Lee, 2016; Myers, 2019). Research is ongoing, with Davenport et al. (2017, p. 1) stating 'we are in the midst of a *revolution* in our understanding of the human microbiome' [emphasis added].

Because microbiomes are essential to many aspects of being human they are framed by social scientists a vital parts of assemblages of more-than-human bodies. Humans are therefore 'superorganisms' (Greenhough et al., 2018, p. 2), with 'being human [labelled]… a multispecies achievement, dependent on the "corporeal generosity" of microbial life' (Lorimer, 2016, p. 58). However, any discussion of human-microbial relationality cannot ignore the relational ontologies, sovereignties, and scholarship of Indigenous peoples without risking appropriation and erasure (Porter et al., 2020; Tallbear, 2011; Todd, 2016; Watts, 2013). Further, considering more-than-human thinking and kin relations and ontologies, Indigenous, Black, Queer and feminist scholars are leading the way in renewed discussions of relationality (Benezra, 2022; Tallbear, 2011). While simultaneously reclaiming relational concepts such as kin (e.g., Kanngieser & Todd, 2020), they are showing how microbes 'take up new (old) kinship formulations … [as] oddkin, chemical kin, cohort kin, environmental kin, situated kin [and] Land/body relations' while arguing for relational accountability (Benezra, 2022, p. 512).

Benezra (2020, p. 828) also writes about the problematic absence/presence of race in human microbiome research: 'Race becomes a ghost in the scientific work, an invisible, powerful informant that affects the categorization of bodies, how difference is scientifically made and verified, and ultimately how interventions and care are applied.' Microbiome research skates on a thin edge if it unproblematically characterises certain human communities or individuals as having microbial relations based on racial profiles and/or other lines of differentiation such as disability, gender or sexuality. As Benezra (2022, p. 512) argues, there is 'a pressing need to decolonize ontological studies of nonhumans, particularly microbes' because of their association with disease and abnormality.

Since most animal-microbial relations are beneficial, symbiotic, or neutral rather than harmful (Greenhough et al., 2018; Haraway, 2016; Yong, 2016), terms such as the 'holobiont'[2] have been used to capture the idea that humans and other animals, along with their microbiomes, are always multispecies communities rather than individual organisms (Robinson & Jorgensen, 2020). The idea of beneficial human-microbial relations formed through long evolutionary associations between people and specific microbiota has been called 'the old friends' hypothesis' (Flies et al., 2017; Robinson & Jorgensen, 2020). However, since germ theory emerged in the mid-1800s, the focus has been on the negative impacts of microorganisms (Robinson & Jorgensen, 2020).

More recently, Robinson and Jorgensen (2020, p. 340) observe, 'the potentially vital role that symbiotic environmental microorganisms play in regulating our health has been neglected'. For example, Flies et al. (2017) discuss how urban humans have been found to have less diverse gut microbiomes, concluding, as have the World Health Organisation, that it is increasingly clear a diverse microbiome is essential to human health (WHO & SCBD, 2015). This conclusion has direct implications for further problematising the uneven distribution of wealth in cities where poorer neighbourhoods will have less diverse and possibly harmful microbiomes compared to wealthier areas. The absence or low biodiversity of microbes in environments and bodies is beginning to be associated with many largely non-communicable diseases and conditions, including Alzheimer's, inflammatory bowel and skin diseases, obesity, allergies, and depression (see Robinson et al. (2020), Lorimer (2017), Mills et al. (2017; Myers, 2019)). The connection between environmental and human microbiomes is so strong that environments are now considered to be more important than human genetics in shaping gut microbiomes (Robinson et al., 2020).

Although the concept remains controversial (Lorimer, 2017; Robinson & Jorgensen, 2020), the idea of 'dysbiosis' has been used to explain the correlation between non-communicable diseases and urban living. Dysbiosis, 'or "life in distress" is considered by some researchers to manifest as an imbalance in the microbial assemblages in the human body to a state that is detrimental to health' (Robinson & Jorgensen, 2020, p. 340). These imbalances can be due to the absence of some microbes ('old friends'), the presence of others that may be pathogenic, and the complex relations within and between microbiomes and their human hosts (Lorimer, 2017) in the built environment. For example, Leung and Lee (2016) discuss a recent review that suggests occupant's mental wellbeing could be improved by reducing exposure to numerous bacterial and fungal species often found indoors.

The rising incidences of auto-immune and inflammatory diseases (Hodgetts et al., 2018), converging with the increasing knowledge about the benefits of microbes means that the treatment of dysbiotic conditions may be about to dramatically improve. Yong (2016, p. 215) reports that 'microbiome manipulators… are developing cocktails of beneficial microbes' that can be consumed to correct dysbiosis and prevent illness, as well as transplanting entire [microbial] communities from one individual to another.' Using Haraway's concept of companion species, Beck (2021) studied participants' experiences of faecal microbiota transplantation (FMT). She found that FMT users described 'how they became observant to how the microbiome expressed itself through bodily functions and what these expressions felt like as a form of communication; a heightened bodily sense … [or] a corporeal dialogue, where the bodily sensations are observed with an increased awareness' (Beck, 2021, p. 368).

Across ecosystems as well as human bodies, Lorimer (2020) discusses these ideas in detail in his book, 'Probiotic Planet: Using Life to Manage Life'. New knowledge about microbes, the invention of technologies to manipulate them, consumption and land use change mean, 'the interactions between human, viral, animal, and technological bodies are becoming more and more intense' (Bennett, 2010, p. 108). It also means that it is 'becoming increasing [ly] hard to hold human life apart from materiality and to deny agency to all forms of life except humans' (Greenhough, 2010, p. 37). Multispecies problems such as pandemics and the acceleration of antimicrobial resistance (Doron & Broom, 2019) indicate there is an urgent need to develop a broader, relational understanding of human-microbial relationships.

## 4 | MORE-THAN-HUMAN CARE TO RESET HUMAN-MICROBIAL RELATIONS

One first step to reset human-microbial relations is try to make microbes more 'visible' or 'relatable', to allow new (old) ways of 'thinking-with' and thinking-through microbes to emerge (Hird, 2009). Although geographic and cognate literature has brought attention to various, numerous human-non-human relations that are taken for granted, there is a bias toward visible, more relatable, macroorganisms (Greenhough et al., 2018; Tallbear, 2011) (e.g., Hitchings, 2003; Philo, 1995; Power, 2012). Taking note of this imbalance, invisible lifeforms and elements of various kinds have been receiving growing consideration from geographers examining finer scales of more-than-human and multispecies assemblages, including those working with Indigenous ontologies (e.g., Barker, 2010; Bawaka Country et al., 2015; Krzywoszynska, 2019; Lorimer, 2020; Robertson, 2020; Tynan, 2021), and when such relations become pathogenic (e.g., Graham, 2015; Greenhough, 2012; Hinchliffe, 2015; Hinchliffe et al., 2013; Lorimer, 2017). In terms of affirmative microbiopolitics, the work of Puig de la Bellacasa (Puig de la Bellacasa, 2017, 2019) on soils has also been influential in drawing attention to working at different, generally smaller, scales. As she explains 'what soils are conceived to be, visions and concepts of soil, will affect the ways they are cared for' (Puig de la Bellacasa, 2019, p. 393). Applied to microbes and microbiomes, how they are conceptualised determines how we treat, respond to, and care for them. Puig de la Bellacasa's (2019) position on visibility is that 'making them visible, come [s] with a message: knowing soils better could enable better care.' One way of achieving greater visibility is through 'envisioning', encouraging familiarity with the teeming forms of microbial life via art-science collaborations (Puig de la Bellacasa, 2019). The idea is that using art and visual media to zoom in and illuminate microscopic scales will evoke new affects and make the liveliness of microbes more real through representational visibility (Puig de la Bellacasa, 2019). The idea of making microbes more visible is echoed in the work of several other scholars. In referring to the greater availability of DNA sequencing for use in homes and workplaces Hodgetts et al. (2018, p. 8), state that, 'the social sciences and humanities can help to map public understandings of microbes and to enable the collaborative development of new ways of seeing the microbial world.' Robinson and Jorgensen (2020, p. 345) propose that, 'technologies and disciplines can now be combined to gain a better understanding of the structure, distribution, and functional roles and relationships of microbial communities within and across different landscapes.' In proposing a new field of microbioscape research,[3] they suggest further that it 'could also be applied to incorporate other perspectives such as new materialism' (Robinson & Jorgensen, 2020, p. 340).

Along these lines, Hird (2009, p. 1) puts forward the notion of 'microontologies', which she describes as referring 'to a microbial ethics, or … an ethics that engages seriously with the microcosmos.' Puig de la Bellacasa (2019, p. 396) explains further that we need to find the 'everydayness by which humans and non-humans are engaged in intensifying intimate entanglements of ecological care'. Care has a particular interpretation in this work as a non-normative obligation, as a 'more than an affective-ethical state: it involves material engagement in labours to sustain interdependent worlds' (Puig de la Bellacasa, 2012, p. 198). Originating from Indigneous ontologies, this sentiment is echoed in geographical literature on care (e.g., Bawaka Country et al., 2013; Greenhough, 2011; Houston et al., 2018; Power & Williams, 2020; Tynan, 2021). However, perhaps what distinguishes microbial relations from other multispecies relationships is their essential nature; we arguably need them more than they need us (Beck, 2021).

Beck (2021, p. 372) advocates for paying more attention to bodies and their multispecies relations via corporeal communication such that we can 'take back our personhood in relation to the nonhuman within us'. Her work with participants having FMT showed how other affects, senses and sensations other than vision are enrolled in understanding the very personal human-microbial relations at play in digestion. A more open sensory and affective approach, rather than only making microbes visible, involves noting what some might feel, smell and taste like. But beyond human bodily interactions with microbes, caring for and with broader microbial relations in urban environments is a way of scaling up to reveal other more-than-human relations; in this sense, microbes or microbiomes could be 'a facilitator … rather than the object' (Greenhough et al., 2018, p. 8).

To conclude, in the final section I reflect on the ideas discussed earlier in the paper to frame future research directions in light of current global challenges.

## 5 | FUTURE GEOGRAPHIC RESEARCH ON HUMAN-MICROBIAL RELATIONS

Although the simplicity of casting microbes in black and white, binary terms, such as 'pathogenic' or 'beneficial' is appealing, it produces an enormous disservice to human and non-human life through the dismantling and reduction of multifaceted and lively relations to homogenisation and individualisation, neutralising power structures, and ignoring multiple forms of vulnerability. As geographers and other scholars are already doing, there is a need to continue to reach out across disciplines and specialisations to pursue lines of enquiry that are relational and ethical, following 'the knots of relating through which human actors and their more-than-human counterparts mutually construct one another' (Clark & Hird, 2018, p. 18). The productive work involved in the reconceptualisation of human-microbial relations is key here, in light of what Mol (2002 p. vii) refers to as 'ontological politics', where concepts, language and framing can determine 'the way in which problems are framed, bodies are shaped, and lives are pushed and pulled into one shape or another'.

The pandemic will no doubt spur on future research on microbes and microbiomes, but based on the material discussed in this paper there are three clear, not necessarily discrete, ways geography and geographers can productively continue to contribute:

1. **Working with scholars of relational and critical theories.** Acknowledging the work that has already been done, there is further scope for geographers to work with and learn from feminist, post-colonial, and other critical theorists to analyse whose bodies are or are not normalised or pathologised in microbiome research and what this means for decolonisation and the achievement of social and ecological justice. Without such critical takes, problematic associations are likely to continue to be made between certain health states and particular races, abilities, and genders, leading to potentially perverse and/or harmful outcomes in the sharing of knowledge about

microbial relations. Beyond this, there is further work and learning to be done in understanding how to live ethically with microbiomes through ideas of kinship and biosociality. The relational scholarship of Indigenous, Black and Queer geographers, along with those from cognate fields, is already leading these applications (e.g., Kanngieser & Todd, 2020; Lobo, 2019; Tuck et al., 2022; Tynan, 2021). There is an ethical responsibility from other scholars writing on microbes and microbiomes to listen to and elevate these voices through citational and other research practices. Collectively, this work will be invaluable in guiding and critiquing the future directions of, and new knowledge generated by, human microbiome and related research and the disciplines and technologies supporting and enabling it.

2. **The study of the settings and practices of everyday life and their various sociomaterial complexities.** Geographers have made substantial contributions to understanding the routines, experiences and impacts of everyday life, and there is ample opportunity to give further attention to detailed human-microbial relations embroiled in daily routines as it takes place in (and on the surfaces of) homes, workplaces, educational and other institutions, and more broadly in urban environments, including in soil, air and as part of complex relations and ecologies with plants and other animals. Research to date has concentrated on human gut-microbial, and to a lesser extent, respiratory, relations; but as the discussions in this paper illustrate, there are many more ways microbes and humans are entangled in an everyday sense, literally, including the novel ecologies in the buildings we inhabit and with the foods, chemicals and other products that we use and consume, our contact with each other, and contact with other macro species. Exposure to microbial ecologies is mediated through the quality, safety, and functionality of the built and other environments we occupy and share. With a suite of methodologies and methods available to them, geographers are ideally placed to study and understand how modification of the design and use of urban environments post-COVID-19, in light of heightened concerns about cleanliness and a rejuvenated fear of microbes, changes everyday practices and vice versa. This could follow on from recent work about ventilation practices (Hitchings & Lee, 2008; Shove et al., 2014), coping with heat (Oppermann et al., 2018), adaptation to weather (de Vet, 2013; Wright & Tofa, 2021) and the comforts and discomforts of living life outdoors (Hitchings, 2021).
3. **The spatial, temporal, and affective dimensions of multispecies-microbial relations.** Microbes are (and are being) enrolled in multifaceted, globally relevant problems such as climate change, biodiversity loss, waste management, and technological human health advances such as FMT and cancer treatment. The COVID-19 pandemic will also generate a renewed interest in their mobility, circulation and flow in local and global networks, extending the work of Clark and Hird (2018) and Ali and Keil (2007). Concerns about future pandemics and the identification of potentially harmful viruses and bacteria provides a compelling narrative sustaining binary conceptualisations of microbes that are 'good/bad', or 'beneficial/pathogenic'. Geographers have an important role in continuing to develop more nuanced understandings of the complex spatial, temporal, scalar, and affective dimensions of human-microbial and other multispecies relations to shift narratives away from binaries to focus on relations that are specific to space and time, their dynamics and mobility. In the context of urban greening and 'rewilding' agendas, there are also opportunities to further understand the impacts of colonisation and the inherent urban inequalities from a microbiomic perspective, including how impoverished, toxic or otherwise unhealthy microbial environments are distributed and maintained in cities, who is most impacted by them, and how they can be remediated.

Using a microbial lens, this paper has shown that the intensity of human-environment relations are much greater, more detailed, and more omnipresent, than is currently accepted. As knowledge of microbes and microbiomes increases, it will further illuminate and politicise the complexities of microbial and multi-scalar ecologies, and how these are vulnerable to, and implicated in, the global challenges affecting all life, nominally the extinction crisis and climate change (Díaz et al., 2019; Karki et al., 2018). Pertinent is the fact that only a tiny fraction of microbes is currently identified. Meanwhile, the melting of polar icesheets and glaciers caused by climate change is reanimating microbes from previous geological epochs who are (re)entering ecosystems that have not encountered them for millennia, or ever (Clark & Hird, 2018). But rather than a broad-brush approach, what might now be most valuable is the disaggregation of microbial genera (and species) in various settings and practices such that different relationships with viruses, fungi, bacteria, algae and protozoa can be better understood and, arguably, cared for.

Just as Robinson and Jorgensen (2020) argue that landscape researchers can make an important contribution towards rekindling old friendships between humans and microbiota, this paper has contended that geographers and other social scientists also have much more to offer resetting human-microbial relations. Ultimately, geographic contributions of many kinds are urgently needed to ensure an enduring and damaging antimicrobial stance is not the sting in the tail from the COVID-19 pandemic.

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## ORCID

*Cecily Jane Maller* https://orcid.org/0000-0001-8322-2124

## ENDNOTES

[1] 'Rewilding', in referencing 'wild' and implying 'wilderness', is a problematic term that erases Indigenous and or First Nations peoples, their connections to place, knowledge and sovereignty, while perpetuating problematic nature-culture binaries.

[2] Holobiont refers to the collection of organisms, usually 'a host plus trillions of micro-organisms' that spend significant parts of their lives together, symbiotically forming functional ecological units (Robinson & Jorgensen, 2020, p. 340).

[3] 'Microbioscape research is the investigation and application of innovative research methods to characterize and visualize the structure, composition and distribution of environmental microbial communities and their relationships with hosts. Furthermore, Microbioscape research aims to understand the social implications and functional ecology of these communities, focusing on their importance for people, place and nature' Robinson, J. M., & Jorgensen, A. (2020). Rekindling old friendships in new landscapes: The environment–microbiome–health axis in the realms of landscape research. *People and Nature*, *2*(2), 339–349. https://doi.org/10.1002/pan3.10082.

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## AUTHOR BIOGRAPHY

**Dr Cecily Jane Maller** is an Associate Professor at RMIT University's School of Global, Urban and Social Studies in Melbourne. As co-leader of the People and Environment Program she researches human-environment interactions using post-humanist theories and qualitative methods. Although an interdisciplinary scholar, Cecily's work is broadly situated in human geography, specialising in theoretically informed approaches, in particular theories of social practice. Dr Maller has recently published a monograph titled 'Healthy urban environments: More-than-human theories' (2018, Routledge) and was lead editor on 'Social practices and dynamic non-humans: Nature, materials and technologies' (2019, Palgrave Macmillan).

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