CIFAR

Legal Rights of Microbes: Working Paper

Global Health Centre Working Paper Series, March 2025

Anthony Rizk, Louis-Patrick Haraoui
Department of Microbiology and Infectious Diseases, Faculty of medicine and Health Sciences, Université de Sherbrooke, Sherbrooke, Québec, Canada

GENEVA GRADUATE INSTITUTE

GLOBAL HEALTH CENTRE

This working paper is prepared for a workshop supported by the Canadian Institute for Advanced Research (CIFAR) and the Swiss National Science Foundation (SNSF) and organised in collaboration with the Global Health Centre at the Geneva Graduate Institute (IHEID).

Legal Rights of Microbes

Working Paper

Introduction

A change has been underway in how we approach microbes – the microscopic organisms that include viruses, bacteria, yeast, fungi and protists and inhabit large swathes of the world. Microbiome studies, a relatively new field of biology, has marked a shift away from the antimicrobial mindset of 19th century bacteriology which cast microbes as primarily pathogenic material [1] towards a symbiotic view of human-microbial interactions [2,3]. Microbiome studies is enabling what Bapteste and colleagues [4] have called a 'pluridisciplinary epistemic revolution,' one that is focused on ecology, multi-scalar interaction, and 'de-anthropocentrification' – a movement away from the human-centered point of view.

This working paper explores how these advances in microbiology may begin to mark a shift towards non-anthropocentric approaches to microbes in international legal frameworks.[1] What would legal rights attuned to 21st century microbiology look like? With the Rights of Nature (RoN) framework – the global movement towards granting legal personhood and protection to natural entities – in mind, we do not mean the Rights of Microbes (RoM) to be just an extension of RoN. Our proposal here is that microbial communities are not just a new domain into which RoN needs to expand. Rather, we show how microbes form fundamental building blocks of life. To take this "ground up" microbial point-of-view is to begin rethinking legal frameworks in entire sectors, from medicine to nutrition to agriculture. Towards the end of the paper, we put forward two challenges for discussion: Can international legal frameworks recognize the complexity of biological organization as it now appears? Given their vastness, are microbiota even 'conservable' within the biodiversity paradigm? We suggest that our focus may be better placed on protecting and conserving the functions of microbiota rather than individual species or their compositions. The working paper concludes with a summary.

Microbiota: A new lexicon

We have long known that microbes play important roles for living organisms, ecosystems and even planetary biogeochemical cycles [6]. Research in the life sciences has been showing how microbes form intricate, interdependent communities, called microbiota; communities that can be associated with non-living entities such as soil and water or living entities, multicellular organisms. When microbiota are symbiotic with and directly sustain a living multicellular organism, they become part of a holobiont, postulated to be a new unit of biological organization [7]. A new lexicon is

[1] International law can be critiqued for having long maintained a subject/object binary in its frameworks, with the human being often being the central subject around which environments, ecologies, and non-human beings are objectified [5].

emerging in the life sciences (see Box 1), one that is not merely a "semantic upgrade" but meant to capture a more nuanced and complete understanding of the complexity of the biological world [7,8].

BOX 1: LEXICON

- Symbiosis: Two or more species living closely together in a long-term relationship
- Macrobe: A eukaryotic multicellular host (e.g. the human), that forms one component of the holobiont
- Microbiota: the community of microbes in or on a host, including bacteria, archaea, viruses, protists and fungi, that forms another component of the holobiont
- Holobiont: a unit of biological organization composed of an individual host (macrobe) and its thousands of symbiotic microbial communities
- Microbiome: the complete genetic content of the microbiota
- Hologenome: the complete genetic content of the host and the microbiota's genome

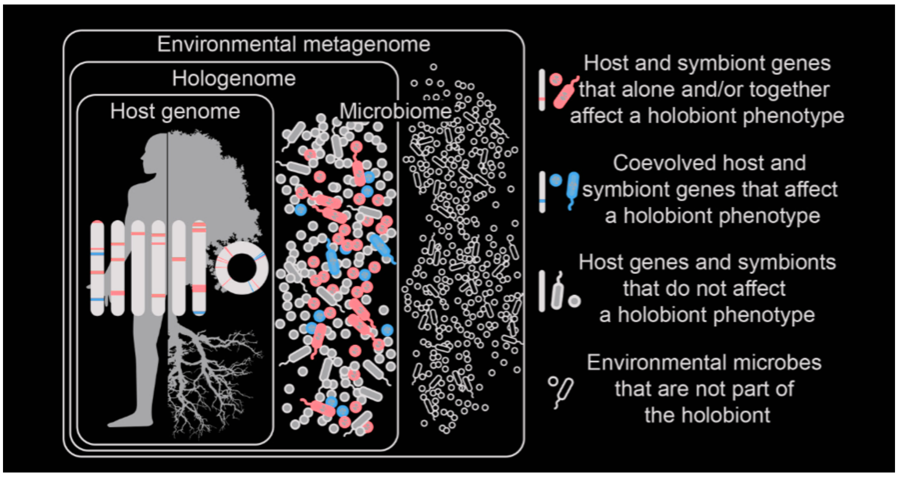
Sources: *Bordenstein and Theis 2015 and Theis et al 2016* [7,9]

Research on microbiota and their microbiomes – their genetic content – shows just how essential they are. Microorganisms associated to a living host have been shown to play essential life-sustaining roles, including in physiology, behavior and reproduction, and across the life span [10–14]. The majority of microbiota are not associated with living organisms and participate in sustaining planetary-scale biogeochemical cycles [15]. Microbiota are fundamental to ecologies [16], architectural design [17], and even our conceptions of selfhood and what it means to be human [2,3,18]. The human gut is estimated to maintain persistent symbiotic relationships with more than 150 species of bacteria, with microbial symbionts maintaining necessary synergisms across the human life cycle [2].

Multicellular living organisms cannot exist in isolation of their associated microbiota. This reasoning has given rise to a new "basic unit of biological organization": the holobiont [19,7]. The Holobiont – derived from the Greek word *holos*, meaning *whole* – is the agglomeration of different organisms into one biological unit, primarily conceptualized as composed of the individual 'host' (the multicellular organism, e.g., the human) and its associated microbiota (the community of symbiotic microbes, e.g., the human gut microbiota) [9,20]. In non-human animals, and especially invertebrates, bacterial symbionts have been shown to carry the genes that enable hosts to synthesize essential amino acids and produce necessary metabolites [21]. Importantly, the symbiotic microbiota is a community – it can be constant or inconstant, harmful, harmless or helpful; all of which varies and is context-dependent [9].

Human and non-human biologies are symbiotic, interconnected and relational [21,22]. It is not just that human health and the sustainability of ecosystems are interconnected with microbiota, but rather that microbiota make them possible to begin with. In other words, microbiome studies shows how we live in primarily microbial worlds. These advances in the life sciences have begun fusing multiple subfields of biology together [7] and transforming other fields and disciplines, from forcing us to reconsider what constitutes a 'healthy' built environment [23] to upending pillars of evolutionary theory [20].

Holobionts: Challenging anthropocentrism in legal frameworks



Theis et al. (2016) Getting the hologenome concept right: an eco-evolutionary framework for hosts and their microbiomes. mSystems, 1(2), e00028-16

The concept of the holobiont challenges long-held anthropocentric preconceptions prevalent in various health initiatives (global health, One Health) as well as in international legal frameworks [24–26]. The human-centered approach has tended to be at the expense of a more expansive eco-centric view of health: the health of other species, of ecosystems, and even of the planet. Recently, the One Health model has been proposed as a tripartite corrective to the human-centered model, combining the efforts of the World Health Organization, the Food and Agriculture Organization and the World Organization for Animal Health to tackle human, animal and environmental health as a united front. Issues such as antimicrobial resistance, zoonotic diseases, and the fallout of environmental degradation are increasingly falling within the remit of the One Health framework. While broader in scope, critics of One Health have already shown how it continues to maintain an anthropocentric bias, where non-human health is only recognized insofar as it has bearing on human health [27,25].

As such, non-human health has yet to be ceded value on its own terms nor has One Health reached the promissory potential of an eco-centric model of health. Pathogen Access- and Benefit-Sharing (P-ABS), for example, has been an area of growing debate around how to govern microbes when they are rendered and exchanged as genetic resources, in service of a vast bioeconomy that has developed around their instrumentalization and use [28–30]. Can microbiome studies and theories of the holobiont make a more eco-centric model of health possible? There have been vocal proponents for giving microbiota further consideration in One Health [31], though Cañada and colleagues [25] argue that a shift in the fundamental 'units of analysis' are needed: firstly, moving away from the individual- or species- level and towards thinking of microbial communities and ecology as a whole and, secondly, recognizing microbes as 'central actors.' Thinking with holobionts can achieves this to a certain extent, though it is not without its shortcomings.

For one, conceptions of the holobiont continue to be bio-centric: they center a multi-cellular 'host' organism alongside an associated microbiota that sustains it, especially ignoring the sheer vastness of microbe-to-microbe interaction [18]. Most microbiota exist irrespective of a multi-cellular host. Flemming and Wuertz [15] have estimated that a vast majority of the planet's microbial cells are ecological entities that inhabit deep oceanic subsurface, deep continental subsurface, upper oceanic sediment, the soil and the oceans, with deep subsurfaces alone estimated to contain 60% of the entire biosphere's microbial cells. Microbiota that are unassociated to any specific multi-cellular organism are in a clear planetary majority, either in the form of 'free' microbial cells or in ecological communities. These microbial communities are major drivers for planetary-scale biogeochemical processes. Most microbiota, then, are not part of a 'holobiont.' They do, however, sustain the conditions that make living organisms – whether human or otherwise – possible.

Secondly, the holobiont has been largely conceptualized as being composed of physical (cellular) and genetic interaction in the 'contact zones' where macro- and micro-scopic organisms meet. It has been possible, then, to map the genetic content of a holobiont, known as the hologenome – all genetic elements that are in contact with each other between the 'macrobe' and the 'microbe.' Many scientists and industries today are engaged in efforts to find 'magic bullets' in human-associated microbiota for health issues, with probiotics and the gut microbiota being a prime example [32]. Such efforts, however, risk positing a kind of microbiotic determinism, similar to claims of genetic determinism that the Human Genome Project sparked in the 1990s and 2000s [33]. A genome-centered agenda is unable to account for instances where the same genetic sequences can perform multiple functions or where changes in genetic expressions occur. Instead of seeing the Holobiont as a cellular-genetic entity, it is also possible to think of the holobiont as a *functional-metabolic* entity. It is not the composition of the microbiota that matters in this instance, but rather, as some research is showing [34], the preservation of its function: what is important is what the microbiota *does*. We will return to this in Challenge 2 below.

Still, the concept of the Holobiont very adequately demonstrates one key point: all living organisms depend on a synergistic microbiota to survive. Across scales, life forms interact across a relational ecology that makes us rethink our basic units of biological organization [35]. If we accept the holobiont, then non-anthropocentric approaches geared towards understanding, sustaining, and protecting microbiota become necessary.

Tackling Dysbiosis: Coming to terms with complexity

For decades, microbiologists have raised concerns about the changing composition and decreasing diversity of microbiota in industrialized societies [36]. Dysbiosis, decreases in microbial diversity and equilibria leading to pathological states has been associated with a wide array of problems – in humans, this has included metabolic syndromes, diabetes, asthma, obesity, ulcerative colitis, depression, multiple sclerosis, Parkinson's disease, Alzheimer's disease, autism, autoimmune diseases including Crohn's disease, irritable bowel syndrome, and lupus [3,27], as well as in animals, insects, plants, with serious consequences for their health and that of ecosystems [4]. On the scale of planetary health, decreasing microbiotic diversity has been identified as a side-effect of agro-industrial settings, including, for example, meat production and the clearing of native forests for logging, increasing urbanization, changing eating habits (e.g., infant formula, processed foods), high rates of Caesarean sections, and the use of antibiotics in human health [37–42].

In other words, the composition and diversity of human microbiomes reflect broader biosocial, historical, political and economic processes. The conceptual purchase of dysbiosis is that it indexes these moments where the composition and diversity of microbiota change and influence human health, demonstrating the intimate relationship between microbiota, multi-cellular organisms, and the world more broadly.

Dysbiosis, however, may have some unanticipated consequences. Dysbiosis may assume that there is such a thing as a 'normal biosis' – a 'normal' distribution or composition of human microbiota. In the anthropology of biomedicine, Lock and Nguyen [43] have already cautioned against assuming the existence of "normal" and "abnormal" bodies, showing instead how biomedicine constructs "normal bodies" through laboratory tests and biostatistical averages, often typecasting benign deviations in metrics and conditions as at-risk conditions or abnormal. Dysbiosis research risks much of the same – in the pursuit of identifying abnormal microbiota, dysbiosis research may be postulating the existence of a 'normal' microbiota, which is unlikely to exist. Rather than seeing the changes we are observing as ones of going from a "normal" microbiota to a dysbiotic one, we can envision these changes as a series of adaptive biologies that are constantly responding to changing conditions. In-roads made in medical anthropology towards thinking of local and situated biologies [44–46], have led to some early work demonstrating how local microbiologies operate [47].

Secondly, dysbiosis is often reduced to meaning less microbial diversity, which opens up the microbial world to global conservation and biodiversity efforts. Cockell and Jones [48] have outlined the difficulties of plans to fold microbes into existing biodiversity and conservation efforts, from the difficulties of species-specific conservation to the rapid multiplication and transformation of microbial populations. The human microbiota alone consists of almost 40 trillion microbial cells that live in and on the human body. Seeking to conserve microorganisms based on their intrinsic value alone and in all cases can quickly become futile. Instead, one possible path is to conserve physical and chemical conditions that best support indigenous microbiota and to prioritize microbial ecosystems that are 1) important to global biogeochemical cycles, 2) involved in regional and local scale cycles, 3) those that have immediate or potential medical or industrial uses and, 4) an intrinsic value in otherwise uninhabited zones (e.g. Antarctic microbes, desert microbes) [48].

There has yet to be enough convincing research that more diversity de facto leads to more functionality of a microbiota, which can range from organism development to biogeochemical processes. Functions of microbiota may be even more esoteric than previously imagined. A microbial 'unconscious' has been postulated, one where the human microbiome is showing influence to our human drives, desires, moods, physical health, mental health and even genetic expressions [49,3]. Such characteristics make microbes appear close to being 'hyperobjects' – objects of such spatial and temporal vastness that they exceed human ability to fully comprehend them [50]. This affects our ability to operate on the microbial world. Biodiversity centers on species-centered cataloguing and preservation. Microbes may be beyond such categorization practices, especially when Lateral Gene Transfer (LGT) is considered.[2] Can the protection of microbes be approached with the same tools that have been used in species conservation? How can we grasp and come to terms with this level of complexity? One possible path forward is thinking about mobilizing legal frameworks as complex adaptive systems – acknowledging the flexible, interdependent and adaptive natures of real-world legal and social systems [51,52]. We will return to this in Challenge 1.

Rights of Microbes: Two challenges to international law

Early work on the rights of microbes has been made by Charles Cockell [6,48,53–56] who, following Christopher Stone's work on the legal rights of natural entities [57], has argued that microbes, as the base for all food chains and major biogeochemical cycles, deserve a special ethical status [6]. This ethical status is due to their 'intrinsic value' to all life, irrespective of instrumental value to specific organisms or processes [6,56]. Since the 1970s, numerous countries have enacted national laws recognizing the rights of nature (RoN), as with rivers, forests, and other ecosystems, providing them with legal protections enforced by governments and upheld in courts. A pragmatic argument for RoN is that human life is entirely dependent on nature, and the only way to work towards healthy ecosystems and human societies is to view nature not only as resources to be exploited, but as having rights in and of itself. Recognizing that nature has rights is viewed as a legal tool to protect it, and ultimately, to protect human life in harmony with nature.

[2] Unlike traditional (vertical) reproduction, later gene transfer is the process through which microorganisms transfer genetic materials across individuals and species.

So far, microbes seem to have been overlooked in RoN and in global biodiversity and conservation actions, despite their foundational role as the first and most essential organisms on Earth upon which all other life depends [58].[3] Many reasons can explain this. Firstly, the focus on microbes predominantly stems from the medical and industrial domains, either as agents of disease or as resources to be harnessed, such as for their antibiotic-producing ability [59] or for use in biochemical processes such as fermentation. Legal frameworks centered on microbes either do so from the perspective of biosecurity – to protect against microbial threats – or to manage them as resources, such as with managing the equitable sharing of benefits derived from their use.[4]

Microbiome research has shown how biology – macroscopic and microscopic alike – is more complex than it first appears. How do we litigate and constitutionalize with this complexity, at a time when more-than-human collectives are increasingly coming center-stage in how we understand our realities [62]? In this working paper, we have resisted the temptation to extend the Rights of Nature (RoN) to a new domain: that of microbiota. We don't intend to argue that microbes need to be seen to have individual rights. Rather, we use the 'rights of microbes' (RoM) to raise the following challenges:

I. *Can international law recognize this level of complexity of biological organization?* To unpack this: To this moment, international law is predicated on the assumption that humans and other multi-cellular organisms are the basic biological units of social organization. Microbial communities have been considered separately from other living organisms: either as pathogens or as resources. If we accept that the biological unit of social organization is not the organism (i.e. the human), but rather the organism and its associated microbiota (i.e. the holobiont), then how can the organism have rights (i.e. human rights) without rights also being conferred to the whole (i.e. the holobiont)? Put another way, how can it be possible to protect human rights without also, by necessity, already protecting the rights of the whole: the rights of the human and its associated microbiota? To render this challenge practical and specific: All human beings are entitled to the highest attainable standard of health, as enshrined in legally binding commitments and international human rights instruments. If the life sciences show that human health is inextricably tied to the health of their associated microbiota (e.g., the microbiota of the human gut) and to the health of the biosphere (e.g. subsurface microbiota), would these microbiota already be conferred, by necessity, a 'right to health'? Or do different legal principles apply?

II. *Can international law protect the functions rather than composition of microbiota?* The discussion paper has shown the pitfalls with treating microbes as individuals, as genetic elements, or as having a 'normal' composition. Firstly, microbes can act as microbiota – as communities –

[3] Although there are signs of movement in the direction of filling this gap with the International Union for Conservation of Nature (IUCN), which governs nature conservation, forming a specialist group for parasite conservation in 2023 [58].
[4] Such as with the Pandemic Influenza Preparedness Framework [60] and the Nagoya Protocol on Access and Benefit-Sharing [61].

rather than as individual species. Secondly, microbiota cannot be reduced to their genetic elements. Arguments have been made for the preservation of the ecosystem functions of microbiota rather than for the individual species per say [6,48]. Is it possible to envision ‘the rights of microbes’ being cast as less of an effort to conserve existing microbiota and their compositions, but rather as a need to catalogue and legally recognize their functions? This constitutes a challenge not only for international law, but an epistemological challenge for the life sciences as well.

Conclusion

Sariola and Gilbert [27] note how symbiosis is “the signature of life on earth.” The human in human health cannot be effectively separated from the social, economic, political, biological and ecological worlds in which they exist. We use the Rights of Microbes (RoM) here to invite a discussion on how international legal frameworks may need to change if they are to take seriously a “grounds up” approach to microbiota and their symbiotic relationship with human, animal and planetary existence. Entire fields of organization of life can be rethought from this vantage point. New institutional necessities emerge, perhaps dedicated to the protection and conservation of microbial ecosystems [6]. Beyond that, sectors such as nutrition, agriculture, and medicine can gain new important dimensions towards the betterment of human, non-human and planetary health. Entire extractive industries would need to be fundamentally altered if we are to become attentive to how human activities affect and transform microbial communities. Unclear still is what the goal is when thinking of rights of microbes. Are we content with preservation and conservation, or can microbiota, like nature, be afforded the right not only to persevere, but also the “right to flourish” [5]? International law, rather than objectifying nature and enabling its extraction, may be a tool that would enable such flourishing to take place.

Authorship

Draft prepared by Anthony Rizk and Louis-Patrick Haraoui for discussion. This draft has benefited from comments from Andrea Fernandez Diaz.

References

1 Latour B. *The Pasteurization of France*. Harvard University Press 1993.

2 Gilbert SF, Sapp J, Tauber AI. A Symbiotic View of Life: We Have Never Been Individuals. *The Quarterly Review of Biology*. 2012;87:325–41. doi: 10.1086/668166

3 Ironstone P. Me, my self, and the multitude: Microbiopolitics of the human microbiome. *European Journal of Social Theory*. 2019;22:325–41. doi: 10.1177/1368431018811330

4 Bapteste E, Gérard P, Larose C, *et al*. The Epistemic Revolution Induced by Microbiome Studies: An Interdisciplinary View. *Biology*. 2021;10:651. doi: 10.3390/biology10070651

5 Jones E. Can the Rights of Nature Transform the Way Rights Are Conceptualized in International Law? In: Rodriguez-Garavito C, ed. *More Than Human Rights: Ecology of Law, Thought and Narrative for Earthly Flourishing*. New York: NYU Law 2024.

6 Cockell CS. The rights of microbes. *Interdisciplinary Science Reviews*. 2004;29:141–50. doi: 10.1179/030801804225012635

7 Bordenstein SR, Theis KR. Host Biology in Light of the Microbiome: Ten Principles of Holobionts and Hologenomes. *PLOS Biology*. 2015;13:e1002226. doi: 10.1371/journal.pbio.1002226

8 Bordenstein SR, The Holobiont Biology Network. The disciplinary matrix of holobiont biology. *Science*. 2024;386:731–2. doi: 10.1126/science.ado2152

9 Theis KR, Dheilly NM, Klassen JL, *et al.* Getting the Hologenome Concept Right: an Eco-Evolutionary Framework for Hosts and Their Microbiomes. *mSystems*. 2016;1:e00028-16. doi: 10.1128/mSystems.00028-16

10 Collins SM, Surette M, Bercik P. The interplay between the intestinal microbiota and the brain. *Nat Rev Microbiol*. 2012;10:735–42. doi: 10.1038/nrmicro2876

11 Cryan JF, Dinan TG. Mind-altering microorganisms: the impact of the gut microbiota on brain and behaviour. *Nat Rev Neurosci*. 2012;13:701–12. doi: 10.1038/nrn3346

12 Ezenwa VO, Gerardo NM, Inouye DW, *et al.* Animal Behavior and the Microbiome. *Science*. 2012;338:198–9. doi: 10.1126/science.1227412

13 Hooper LV, Littman DR, Macpherson AJ. Interactions Between the Microbiota and the Immune System. *Science*. 2012;336:1268–73. doi: 10.1126/science.1223490

14 Tremaroli V, Bäckhed F. Functional interactions between the gut microbiota and host metabolism. *Nature*. 2012;489:242–9. doi: 10.1038/nature11552

15 Flemming H-C, Wuertz S. Bacteria and archaea on Earth and their abundance in biofilms. *Nat Rev Microbiol*. 2019;17:247–60. doi: 10.1038/s41579-019-0158-9

16 Averill C, Anthony MA, Baldrian P, *et al.* Defending Earth's terrestrial microbiome. *Nat Microbiol*. 2022;7:1717–25. doi: 10.1038/s41564-022-01228-3

17 Colomina B, Wigley M. The Bacterial Clients of Modern Architecture. | EBSCOhost. 2020;6. https://openurl.ebsco.com/contentitem/gcd:147586289?sid=ebsco:plink:crawler&id=ebsco:gcd:147586289 (accessed 10 February 2025)

18 Morar N, Bohannan BJM. The Conceptual Ecology of the Human Microbiome. *The Quarterly Review of Biology*. 2019;94:149–75. doi: 10.1086/703582

19 Rosenberg E, Koren O, Reshef L, *et al.* The role of microorganisms in coral health, disease and evolution. *Nat Rev Microbiol*. 2007;5:355–62. doi: 10.1038/nrmicro1635

20 Roughgarden J, Gilbert SF, Rosenberg E, *et al.* Holobionts as Units of Selection and a Model of Their Population Dynamics and Evolution. *Biol Theory*. 2018;13:44–65. doi: 10.1007/s13752-017-0287-1

21 McFall-Ngai M, Hadfield MG, Bosch TCG, *et al.* Animals in a bacterial world, a new imperative for the life sciences. *Proceedings of the National Academy of Sciences*. 2013;110:3229–36. doi: 10.1073/pnas.1218525110

22 Bosch TCG, McFall-Ngai MJ. Metaorganisms as the new frontier. *Zoology*. 2011;114:185–90. doi: 10.1016/j.zool.2011.04.001

23 Bosch TCG, Wigley M, Colomina B, *et al.* The potential importance of the built-environment microbiome and its impact on human health. *Proceedings of the National Academy of Sciences*. 2024;121:e2313971121. doi: 10.1073/pnas.2313971121

24 Kamenshchikova A, Wolffs P, Hoebe C, *et al.* Anthropocentric framings of One Health: an analysis of international antimicrobial resistance policy documents. *Critical Public Health*. 2021;31. doi: https://doi.org/10.1080/09581596.2019.1684442

25 Cañada JA, Sariola S, Butcher A. In critique of anthropocentrism: a more-than-human ethical framework for antimicrobial resistance. *Medical Humanities*. 2022;48:e16–e16. doi: 10.1136/medhum-2021-012309

26 Mbũgua K. Bioethics and One Health: Beyond Anthropocentrism. In: Omutoko L, Jaoko W, eds. *Bioethics from the Global South*. Cham: Springer Nature Switzerland 2024:83–91.

27 Sariola S, Gilbert SF. Toward a Symbiotic Perspective on Public Health: Recognizing the Ambivalence of Microbes in the Anthropocene. *Microorganisms*. 2020;8:746. doi: 10.3390/microorganisms8050746

28 Burci GL, Gostin LO. Privatized Pharmaceutical Innovation vs Access to Essential Medicines: A Global Framework for Equitable Sharing of Benefits. *JAMA*. 2017;317:473–4. doi: 10.1001/jama.2016.17994

29 Rizk A, Bezruki A, Fallah MP, *et al.* Drivers and Barriers to Pathogen- and Benefit-Sharing (PBS): An empirical study of global perceptions and practices and case studies from Ebola in Liberia and Zika in Brazil. *Global Health Governance*. 2022;17.

30 Strobeyko A. The Future of Pathogen Access and Benefit Sharing under International Law. *Verfassungsblog*. Published Online First: 29 March 2024. doi: 10.59704/8345568e8e960109

31 Trinh P, Zaneveld JR, Safranek S, *et al.* One Health Relationships Between Human, Animal, and Environmental Microbiomes: A Mini-Review. *Front Public Health*. 2018;6. doi: 10.3389/fpubh.2018.00235

32 Lorimer J. *The probiotic planet: Using life to manage life*. U of Minnesota Press 2020.

33 Parke EC. Trivial, Interesting, or Overselling? The Microbiome and “What It Means to Be Human”. *BioScience*. 2021;71:658–63. doi: 10.1093/biosci/biab009

34 Schäfer M, Pacheco AR, Künzler R, *et al.* Metabolic interaction models recapitulate leaf microbiota ecology. *Science*. 2023;381:eadf5121. doi: 10.1126/science.adf5121

35 Haraoui L-P. Networked collective microbiomes and the rise of subcellular ‘units of life’. *Trends in Microbiology*. 2022;30:112–9. doi: 10.1016/j.tim.2021.09.011

36 Gillings MR, Paulsen IT. Microbiology of the Anthropocene. *Anthropocene*. 2014;5:1–8. doi: 10.1016/j.ancene.2014.06.004

37 Boyd W. Making Meat: Science, Technology, and American Poultry Production. *Technology and Culture*. 2001;42:631–64.

38 Byers A-K, Condron L, Donavan T, *et al.* Soil microbial diversity in adjacent forest systems – contrasting native, old growth kauri (Agathis australis) forest with exotic pine (Pinus radiata) plantation forest. *FEMS Microbiology Ecology*. 2020;96. doi: https://doi.org/10.1093/femsec/fiaa047

39 Betran AP, Ye J, Moller A-B, *et al.* Trends and projections of caesarean section rates: global and regional estimates. *BMJ Glob Health*. 2021;6. doi: 10.1136/bmjgh-2021-005671

40 Campbell R, Hauptmann A, Campbell K, *et al.* Better understanding of food and human microbiomes through collaborative research on Inuit fermented foods. *Microbiome Res Rep*. 2022;1:5. doi: 10.20517/mrr.2021.06

41 Tanabe K, Monguchi M, Inoue R, *et al.* Lentilactobacillus buchneri domination during the fermentation of Japanese traditional fermented fish (funazushi). *Food Science & Nutrition*. 2022;10:4073–9. doi: 10.1002/fsn3.3002

42 Haraoui L-P, Blaser MJ. The Microbiome and Infectious Diseases. *Clinical Infectious Diseases*. 2023;77:S441–6. doi: 10.1093/cid/ciad577

43 Lock M, Nguyen V-K. *An Anthropology of Biomedicine*. John Wiley & Sons 2018.

44 Lock M. Cultivating the Body: Anthropology and Epistemologies of Bodily Practice and Knowledge. *Annual Review of Anthropology*. 1993;22:133–55.

45 Brotherton PS, Nguyen V-K. Revisiting Local Biology in the Era of Global Health. *Medical Anthropology*. 2013;32:287–90. doi: 10.1080/01459740.2013.791290

46 Niewöhner J, Lock M. Situating local biologies: Anthropological perspectives on environment/human entanglements. *BioSocieties*. 2018;13:681–97. doi: 10.1057/s41292-017-0089-5

47 Koch E. Local Microbiologies of Tuberculosis: Insights from the Republic of Georgia. *Medical Anthropology*. 2011;30:81–101. doi: 10.1080/01459740.2010.531064

48 Cockell CS, Jones HL. Advancing the case for microbial conservation. *Oryx*. 2009;43:520–6. doi: 10.1017/S0030605309990111

49 Zwart H. Towards an Eco-Centric View of Human Existence: Implications of Genomics for the Environmental Zone. 2010.

50 Morton T. *Hyperobjects: Philosophy and Ecology after the End of the World*. University of Minnesota Press 2013.

51 Ruhl JB. Fitness of Law: Using Complexity Theory to Describe the Evolution of Law and Society and Its Practical Meaning for Democracy, The. *Vand L Rev*. 1996;49:1406–90.

52 Soininen N, Ruhl JB, Cosens BA, *et al.* Governing Complexity: A Comparative Assessment of Four Governance Models with Applications to Climate Change Mitigation and Adaptation. 2024.

53 Cockell CS. Planetary protection—A microbial ethics approach. *Space Policy*. 2005;21:287–92. doi: 10.1016/j.spacepol.2005.08.003

54 Cockell CS. Microbial rights? *EMBO reports*. 2011;12:181–181. doi: 10.1038/embor.2011.13

55 Cockell CS. The Ethical Status of Microbial Life on Earth and Elsewhere: In Defence of Intrinsic Value. In: Schwartz JSJ, Milligan T, eds. *The Ethics of Space Exploration*. Cham: Springer International Publishing 2016:167–79.

56 Cockell CS. Microbial Life, Ethics and the Exploration of Space Revisited. *Astrobiology*. John Wiley & Sons, Ltd 2021:233–54.

57 Stone CD. Should trees have standing? - Toward legal rights for natural objects. *Southern California Law Review*. 1972;45.

58 Claerhoudt R. The Legal Protection of Animal Parasites in International Biodiversity Law. *Journal of Environmental Law*. 2024;36:301–22. doi: 10.1093/jel/eqae024

59 Shanahan F. Separating the microbiome from the hyperbolome. *Genome Med*. 2015;7:17. doi: 10.1186/s13073-015-0143-5

60 World Health Organization. Pandemic influenza preparedness framework for the sharing of influenza viruses and access to vaccines and other benefits. 2011.

61 Secretariat of the Convention on Biological Diversity. *The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity*. Convention on Biological Diversity 2011.

62 Fleurke F, Leach M, Lindahl H, *et al.* Constitutionalizing in the Anthropocene. *Journal of Human Rights and the Environment*. 2024;15:4–22. doi: 10.4337/jhre.2024.01.01