Public Humanities (2025), 1, e146, 1–11
doi:10.1017/pub.2025.10065

CAMBRIDGE UNIVERSITY PRESS PUBLIC HUMANITIES

POLICY BRIEF

Overwhelming Complexity? Entering a New Era of Microbial Governance

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(Received 28 May 2025; revised 19 August 2025; accepted 23 September 2025)

Abstract

Climate change, biodiversity loss, and antimicrobial pollution caused by human activity are placing pressure on global microbiota. However, microbial protection remains mostly absent from international law and global governance frameworks. This policy brief highlights the chronic marginalisation of microbes in international health, environmental, and human rights law, as well as in governance frameworks addressing antimicrobial resistance (AMR). Drawing on recent genomics and humanities research, it argues that policymakers need to abandon interventions designed to control or combat individual microbes in favour of microbiota-oriented governance. This brief discusses three major areas (pollution thresholds, microbial conservation, and the human right to a clean, healthy, and sustainable environment) where change is already occurring.

Keywords: antibiotics; antimicrobial resistance; healthy environment; microbial governance; sustainability

1. Our fragile microbial biosphere

In 2023, the International Union of the Microbiological Sciences (IUMS) issued an urgent call to "save the microbes to save the planet."[1] According to the IUMS, the approximately trillion microbial species making our planet habitable are facing intense pressure from human activities, including climate change, biodiversity loss, and mass exposure to antimicrobial substances. Protecting the planet thus entails creating frameworks to protect the microbes. And yet, microbes—including bacteria, viruses, fungi, algae, protozoa, and archaea—remain notably absent from both international law and governance. Of the more than 500 multi-legal instruments issued under the United Nations, few, if any, mention microbes or their importance for human life.[2] This policy brief argues that chronic neglect of microbial environments is not only leading to biodiversity loss and habitat degradation, but also undermining humanity's ability to respond to major global health challenges such as antimicrobial resistance (AMR). Rather than treating microbes as "enemies," "workers," or "bioassets," decision-makers need to develop sustainable ecological forms of microbial

[1] Rappuoli et al. 2023.
[2] Boucrot, Kirchhelle, and Varadan 2025; Crowther et al. 2024.

governance and legislation. Employing a historical perspective, this brief first analyses microbes' marginalised place within international law and governance. It then reviews how emerging debates about antimicrobial pollution, microbial conservation, and the human right to a clean, healthy, and sustainable environment enable new ways of conceptualising interlayered forms of microbiota-oriented governance.

2. Chronic neglect: Microbes' marginalisation in global governance

Governing microbes is challenging. Current assessments hold that at any one time, there are approximately 5 million trillion living bacteria on earth (10^{30})—with up to 40% dying per day—which proliferate at different speeds, exchange genes, and know no borders.[3] It is easy to see why the often overwhelming complexity of this vast microcosm has traditionally made regulators shy away from trying to manage it.

Since the nineteenth century, most deliberate human interventions into the microbial biosphere have focused on controlling a small number of microbial pathogens (ca. 1,400 species; <1% of total microbial diversity) or industrial organisms.[4] Starting with the International Sanitary Conventions and continuing with the International Health Regulations, international health law has been concerned with stopping pathogens from spreading from one location to another.[5] By contrast, microbes that were deemed of economic value to industries such as brewing or pharmaceutical manufacturing became subject to ever more stringent proprietary safeguards. Starting in the 1940s and accelerating from the 1970s onwards, new intellectual property frameworks emerged to secure control over useful bioresources.[6] By the 1980s, recombinant microbes began to be considered intellectual property as such.[7] Environmental laws, such as the 1992 Convention on Biodiversity, sought to ensure that resulting financial and technological benefits were distributed more evenly by introducing sovereign control over microbial resources. However, no formal protection of microbes as such emerged: *in situ* conservation remained focused on macrobial life, and *ex situ* conservation of microbes in culture collections faced pressure due to reduced core funding.[8]

Apparent disregard for most microbes or microbiota under international law and biodiversity conservation is mirrored in other areas of governance—notably attempts to curb AMR. Since the first observation of emergent "drug fastness" in microbes around 1910, rising levels of AMR have led to attempts to safeguard drug efficacy and control the spread of individual "superbugs."[9] Often employing phenotypic "breakpoints" to evaluate antimicrobials' ability to impede clinical isolates of pathogens, officials developed increasingly sophisticated antimicrobial stewardship frameworks to regulate access to and use of antimicrobials.[10] However, by limiting concerns to medical or agricultural settings, functionalist stewardship frameworks failed to appreciate microbiota interlinkages and the wider environmental drivers of AMR.[11]

[3] Rappuoli et al. 2023.
[4] Rappuoli et al. 2023.
[5] Kirchhelle and Podolsky 2022.
[6] Kirchhelle and Vagneron forthcoming.
[7] Rasmussen 2014.
[8] Kirchhelle and Vagneron forthcoming.
[9] Gradmann 2011.
[10] Gradmann 2013; Gradmann and Kirchhelle 2023; Podolsky 2015.
[11] Kirchhelle 2023.

https://doi.org/10.1017/pub.2025.10065 Published online by Cambridge University Press

Over the past two decades, genomic investigations of clinical and non-clinical microbiota have led to a far more ecological understanding of the AMR challenge. Studies highlight that AMR is a natural microbial response to various pharmaceutical and non-pharmaceutical selection pressures—and often associated with wider microbiota shifts.[12] Although AMR predates the modern era by millennia, data from preserved microbial strains, soil archives, and lake sediments show a panspecies increase of AMR across biogeographies during the nineteenth and twentieth centuries. Periods of AMR acceleration have correlated with anthropogenic pressures, such as the introduction of novel broad-spectrum antibiotics and biocides.[13] Fallouts were not evenly distributed. At a societal level, AMR is often most pronounced in poorer communities suffering higher exposure to selective pollution and disease burdens.[14] However, linking specific antimicrobial exposures or environmental AMR reservoirs to instances of human or animal harm remains challenging.[15]

Unfortunately, few insights on multifactorial drivers of AMR and microbial stress have been translated into policy. Instead, AMR governance remains dominated by linear cause-and-effect models based on triaging and stewarding a limited number of pharmaceuticals in accordance with 1990s usage regimes from high-income countries.[16] Whether these stewardship regimes are effective is unclear. According to a twenty-year evaluation of European AMR data, regional fluctuations of AMR were only weakly correlated with shifting antimicrobial use in hospitals and reflected hitherto underexplored ecological factors.[17] While this policy brief is not a call to abandon antimicrobial stewardship, it is clear that regulating AMR requires new ecological governance frameworks capable of actively managing microbial environments.

3. Ecological governance: Managing the microbial commons

Engaging with nonlinear microbiota dynamics opens the door for broader debates on microbial health and equity. Over the past decade, a growing number of commentators have started to contemplate ways of viable microbial governance beyond existing antimicrobial templates.[18] Given the complexity of microbiota, magic bullet solutions are unlikely, and proactive governance will entail sociopolitical trade-offs. So far, three distinct schools of thought have emerged: establishing thresholds for antimicrobial exposure, enhancing microbial conservation, and integrating microbes into human rights legislation. All three approaches are imperfect but offer incremental and interlayerable approaches towards more sustainable human–microbial relationships.

3.1. Pollution thresholds

Since around 1800, establishing thresholds to demarcate levels at which exposure to hazards becomes (in)acceptable has become a key technique of industrial regulation.[19] In the case of antimicrobial pharmaceuticals, which can impact a wide range of microorganisms due to selection for cross-resistance and habitat shifts or loss, thresholds have only been applied

[12] Despotovic et al. 2023; Hwengwere et al. 2022.
[13] Hendriksen et al. 2019; Knapp et al. 2010; Munk et al. 2022; Yan et al. 2024; Zheng et al. 2022.
[14] Keenan et al. 2025.
[15] Kahn and Dunham 2023.
[16] Podolsky 2018.
[17] Emons, Blanquart, and Lehtinen 2025.
[18] Crowther et al. 2024; Dominguez-Bello et al. 2025; Rappuoli et al. 2023.
[19] Boudia and Jas 2014; Jarrige and Le Roux 2020; Kirchhelle 2018.

https://doi.org/10.1017/pub.2025.10065 Published online by Cambridge University Press

selectively.[20] While the past 150 years have seen farms and clinics subjected to increasingly stringent stewardship regimes, human and animal effluent, as well as pharmaceutical manufacturers, have mostly escaped AMR-focused regulation.[21] This omission is starting to change. Following warnings about the selective impacts of industrial and medical waste, the past decade has seen efforts to establish thresholds for antimicrobial effluent at both the national and international levels.[22] Currently, significant effort is being devoted to establishing predicted no-effect concentrations (PNECs) below which discharge is considered safe.[23]

Just like other historical threshold debates, establishing PNECs is an epistemically and politically fraught process involving powerful economic interests and adjudicating between often competing scientific expertise.[24] Tensions are particularly high regarding PNECs for industrial waste. Between 2019 and 2021, India launched ultimately abortive attempts to introduce statutory limits on antibiotic concentrations in treated effluents and sludge.[25] The initiative triggered resistance from Indian manufacturers and the international AMR Industry Alliance, which had published its own voluntary guidelines in 2018.[26] Resulting debates centred not only on technical questions such as where to monitor for selective effects, but also on broader issues such as the "ordinary" selectiveness of urban as opposed to industrial waste and how to disentangle current selection from pre-existing multifactorial pollution.[27] A particularly interesting debate centred on how to set baselines for "intact" microbiota. Whereas AMR norms have traditionally originated in the Global North, the discharge controversy saw Indian scientists push back against international researchers' use of Scandinavian lakes as controls to evaluate dysbiotic dynamics in Indian biogeographies.[28] Controversies have not died down. 2024 World Health Organization and UN Environmental Programme wastewater guidelines, based on consultations with aforementioned international scientists, are notably stricter than those of the AMR Industry Alliance—and have triggered new research on PNECs and microbial harm.[29] However, other non-pharmaceutical forms of antimicrobial pollution, such as biocides or heavy metals, often remain exempt from current microbiota-oriented threshold discussions.

Although historians have highlighted regulatory thresholds' role in legitimising pollution and supporting industrial over community interests, the current absence of meaningful guidelines for microbiota protection and the need for ongoing antimicrobial use means that emission-like limits will be a core component of future microbial governance.[30] Meanwhile, emerging debates about environmental regulation of antimicrobial pollution are leading to the rapid formalisation of previously abstract concepts, such as healthy "eu" and "dysbiotic" microbiota.[31] Antimicrobial pollution debates are also raising questions about which

[20] Sams-Dodd and Sams-Dodd 2025; Sekyere and Asante 2018; Wallace et al. 2023.
[21] Thornber et al. n.d.; Kirchhelle 2020; Podolsky 2018
[22] CIDRAP-AST 2022; Harris et al. 2014; Rogowska, Gałęzowska, and Zimmermann 2024; Sidrach-Cardona et al. 2014; UNEP/WHO 2024.
[23] Murray et al. 2021, 2024.
[24] Vogel 2012.
[25] CIDRAP-AST 2022.
[26] AMR Industry Alliance 2018; CIDRAP-AST 2022.
[27] CIDRAP-AST 2022.
[28] Bjerke 2025; Overton et al. 2021.
[29] Keane et al. 2025; Murray et al. 2024; UNEP/WHO 2024.
[30] Doron and Broom 2019.
[31] Bengtsson-Palme et al. 2019; 2023; Kotwani et al. 2023; Kotwani, Joshi, and Kaloni 2021.

https://doi.org/10.1017/pub.2025.10065 Published online by Cambridge University Press

microbes or microbiota should be prioritised for *in situ* protection (see below).[32] Expanding the threshold concept to the planetary level, some researchers have called for antimicrobial exposure to be integrated into the Stockholm Resilience Forum's planetary boundaries framework to ensure the integrity of vital microbial services for human, animal, and plant life.[33]

3.2. *Microbial conservation*

Concerns about antimicrobial pollution and biodiversity loss have driven advocacy for microbial conservation. Over the past thirty years, a growing number of microbiologists and exobiologists have called on regulators to widen One Health approaches to encompass microbial ecologies and to actively conserve certain environments to prevent microbial extinction.[34] Often referring to undiscovered applications and scientific breakthroughs, researchers and organisations, such as the IUMS, emphasise the future value of rare, extreme, or as yet mostly undisturbed habitats such as the deep sea.[35] While this form of microbial conservation is not designed to foster stewardship of already disturbed microbiota, it aligns with existing biodiversity and intellectual property frameworks.[36] Similar to what geographer Jamie Lorimer describes as a probiotic turn, the quest to protect, collect, and ultimately exploit "undisturbed" microbiota also forms part of growing industrial and biomedical efforts to "rewild" modern microbiota.[37]

Intensifying existing conservation approaches is not uncontentious. The abovementioned Convention on Biodiversity and the subsequent Nagoya Protocol have tried to distribute benefits resulting from biodiversity conservation and exploitation.[38] However, *ex situ* storage remains concentrated in wealthy countries, benefit distribution has been marginal, and indigenous groups have criticised state-focused conservation frameworks. Scientists have also highlighted how sovereign or IP-based ownership structures impede microbial exchange and commons-based preservation. Meanwhile, *in situ* conservation of rare environments continues to focus on macrobial life.[39]

While intensified conservation is unlikely to overcome these entrenched challenges, associated investment in analysing and stabilising fluid microbiota is leading to important insights about microbial diversity and the differential impacts of microbial stressors.[40] It has also triggered debates about whether all forms of microbial biodiversity need to be conserved or whether efforts should focus on maintaining microbiota that are critical for human life and well-being (see below).[41] Growing interdisciplinary engagement with how to define and maintain "undisturbed" microbiota also raises important questions about how to distribute resulting benefits and compensate for historical pollution burdens (see above).[42] Perhaps most importantly, portraying the microbial assemblages we depend on as a finite

[32] Rizk et al. 2025; Trevelline et al. 2019; Webster, Wagner, and Negri 2018.
[33] Kirchhelle and Roberts 2025; Richardson et al. 2023.
[34] Cockell and Jones 2009; Colwell 1997; Crowther et al. 2024; Dominguez-Bello et al. 2025; Fernandez Diaz et al. 2025; Griffith 2012.
[35] Casamayor 2017; Rappuoli et al. 2023; Webster et al. 2018; Zucconi et al. 2025.
[36] Kirchhelle and Vagneron forthcoming.
[37] Ferrari, Raffaetà, and Beltrame 2024; Lorimer 2020; Schnorr et al. 2014.
[38] Reichman, Uhlir, and Dedeurwaerdere 2016.
[39] Bader et al. 2023; Kirchhelle and Vagneron forthcoming; Salem and Kaltenpoth 2023.
[40] Bodelier 2011.
[41] Webster et al. 2018.
[42] Ishaq et al. 2019; 2021.

https://doi.org/10.1017/pub.2025.10065 Published online by Cambridge University Press

commons is laying the foundations for new conceptualisations of microbes as fundamental for the exercise of human rights.

3.3. Rights to microbes and microbial rights

Originating in the decades after 1945, modern human rights law has mostly focused on inter-human rather than interspecies relationships.[43] This exclusive focus is beginning to change. A 2025 advisory opinion by the International Court of Justice noted that states have a legal obligation to protect the climate as a way of protecting human rights—thus explicitly connecting the formerly distinct domains of human rights and environmental law.[44] Protecting critical microbiota would mark a logical extension of this principle. Two distinct approaches are emerging.

Drawing on legal precedents that have seen personhood status applied to natural bodies, such as rivers and watersheds, some scholars have called for microbes to enjoy basic rights as a way to overcome the anthropocentric marginalisation of environments.[45] There are several conceptual challenges with this approach: the inherent evolutionary fluidity and community structure of microbiota means that concepts of individual personhood are difficult to apply; certain microbial assemblages can thrive in polluted environments that are not beneficial to human, animal, or plant life; and some microbial assemblages—including pathogens—are actively harmful to human life. As highlighted by Kathryn Yusoff and Myra Hird, imagining that microbial life and evolution aim for symbiotic states with or "care" for human life is itself an anthropocentric fallacy.[46]

Inspired by bioeconomic concepts of ecological services, other researchers have proposed a right to microbes or protecting crucial microbial services within the newly recognised human right to a clean, healthy, and sustainable environment (see also Boucrot et al in this thematic collection).[47] Ongoing scientific knowledge gaps and the inability to protect all microbes mean that future conservation priorities will inevitably be influenced by the relative importance of "services" that different microbiota render to human, animal, and plant life. This services approach does not seek to overcome the inherent anthropocentricism of international human rights law, fails to value biodiversity as such, and can struggle to deal with trade-offs between different ecoservices.[48] It, however, offers epistemic flexibility when it comes to defining what counts as a functional or damaged human–microbial constellation. Rather than requiring unwieldy universal definitions of eu- or dysbiotic microbiota, communities and courts can define "useful" or "healthy" microbiota, as well as harms to local microbial services, in a bottom-up fashion.

The described bottom-up approach of legal redress is no panacea. Microbes are currently not mentioned in the relevant UN General Assembly declaration or enacted national and regional legal instruments.[49] In terms of planetary health, individual rulings will also not replace the need for enforceable international pollution thresholds or coordinated microbial

[43] Mégret 2023.
[44] ICJ 2025; Schlößer and Eshke 2025.
[45] Cockell 2011; Gordon 2018; Rizk et al. 2025; Rizk and Haraoui 2025.
[46] Hird and Yusoff 2019.
[47] Boucrot et al. 2025; Lele et al. 2013; Rizk et al. 2025; Rizk and Haraoui 2025; UNGA 2022; Varadan et al. 2024.
[48] Lele et al. 2013.
[49] Boucrot et al. 2025; UNGA 2022.

conservation. By itself, legal action is moreover insufficient to achieve an equitable transition away from (anti)microbial injustice.[50]

The possibility of legal redress nonetheless adds "teeth" to current threshold debates and may also galvanise state action to conserve critical microbiota. The ability to extend definitions of AMR-related harms beyond therapy failure could also trigger an ecological reformulation of antimicrobial stewardship. Whereas current stewardship foregrounds the protection of drug efficacy and individual responsibility for appropriate usage, a broader environmental definition of AMR-related harms could lead to ecological stewardship systems that take into account differential responsibilities for historical and current pollution and address non-pharmaceutical selection.[51] Overall, the new human right's ability to foreground microbes' importance for environmental and human health and epistemic flexibility when it comes to prioritising services offers a powerful way to overcome decades of fragmented legal conceptualisations of microbial life.

4. Conclusion: Ecology and equity

The current intersection of calls for *in situ* microbial conservation with debates on antimicrobial thresholds, rights to microbes, and the international recognition of the right to a healthy environment is indicative of a wider ecological turn when it comes to conceptualising human health. In contrast to the previous century's focus on microbial control and drug efficacy, growing awareness of the interconnectedness of microbial ecologies and the unequal fallouts of selective pressures are leading to a new focus on microbial management. Relevant debates about "healthy" baselines and how to define no-effect concentrations are already taking place. Fragmentary knowledge about microbiota means that new regulations will be imperfect and that future governance will likely "fudge" all three outlined approaches. In this situation, decision-makers need to ensure the regular review of emergent standards and guarantee that new ecological frameworks also address the unequal distribution of pollution burdens and access to the microbial commons.

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Acknowledgements. The author would like to thank Drs Wendy Boucrot and Sheila Varadan for their valuable comments on the manuscript.

Author contribution. Conceptualization: C.K.

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[50] Varadan et al. 2024.

[51] Boucrot et al. 2025.

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Cite this article: Kirchhelle, Claas. 2025. "Overwhelming Complexity? Entering a New Era of Microbial Governance." *Public Humanities,* 1, e146, 1–11. https://doi.org/10.1017/pub.2025.10065