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Perspective

Microbiomes for a stable planet: Embedding microbial processes in global climate action

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ABSTRACT

Microorganisms regulate key biogeochemical processes and ecosystem feedbacks to climate change, yet they remain underrepresented in global environmental policy and implementation frameworks. The World Microbiome Partnership (WMP) Environment and Climate Change Roadmap sets out a coordinated agenda to embed microbial science into climate mitigation, adaptation, and nature-based solutions. It identifies three scientific priority actions: (i) microbial process accounting, (ii) global integration of microbiome data, and (iii) the deployment of microbiomes for ecological resilience. These priorities define the core knowledge and governance gaps that currently limit the effectiveness of climate mitigation, adaptation, and nature-based solutions. To operationalise these priorities, the Roadmap establishes interoperable microbiome data infrastructures linking distributed observations across biomes, a federated governance model combining regional stewardship with global standards, and measurable microbial indicators translated into policy-relevant targets for climate, biodiversity, and ecosystem rehabilitation. The roadmap proposes alignment with existing climate and biodiversity agreements to avoid duplication and maximise impact. By articulating concrete near-term priorities and cross-sector partnerships, this comment aims to catalyze coordinated investment and action so that microbial systems are recognized, protected, and harnessed as essential components of a stable and just climate future.

1. Introduction

1.1. Re-grounding "One Health" in the microbial world

“One Health”, an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems, is championed by the World Health Organization (WHO), the Food and Agriculture Organisation (FAO), the World Organisation for Animal Health (WOAH), and the United Nations Environment Programme (UNEP). Yet its implementation often overlooks the microbial foundations of planetary health that sustain the health of people, animals and ecosystems.

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1.2. The invisible yet powerful climate engineers

Microbial communities drive the biogeochemical machinery that makes planet Earth habitable [1]. They regulate carbon, nitrogen and methane fluxes, stabilize soils and oceans, and buffer ecosystems against climatic extremes. Despite this, microbes remain missing from the frameworks that steer climate mitigation, adaptation, conservation, and ecosystem rehabilitation.

Post 30th meeting of the Conference of the Parties (COP30) in Belém, Brazil, home to one of the planet's largest microbially mediated carbon sinks, it is time to recognize environmental microbes as central actors in the "One Health" and climate agenda. Incorporating microbial processes into climate and health governance would bridge long-standing silos between environmental and biomedical policy, moving from fragmentation toward interoperability. Doing so is not merely academic: it is essential for building resilient, life-supporting systems in a rapidly changing world.

1.3. From genes to global fluxes

Across soils, freshwater, sediments, oceans, and the atmosphere, microbial metabolisms regulate the balance between carbon sources and sinks. In soils, enzymatic decomposition determines carbon residence time [2]. In the ocean, microbial networks drive the biological carbon pump [3], while viruses shape its efficiency through infection cycles [4]. In permafrost and wetlands, microbial guilds govern the fluxes of methane [5], the second most important greenhouse gas only after CO_2.

Yet Earth System Models (ESMs) still treat microbial processes as static "black boxes", largely due to the inability to accurately detect, monitor and mine their metabolic functions in a real-time, scalable and globally coordinated fashion. This simplification has obscured the enormous contribution of microbiomes, masked their dynamic feedbacks that can either amplify or dampen warming, and left their ecosystem-remediatory power largely untapped. Recent advances in real time high-resolution molecular profiling, single-cell analytics, and interoperable data infrastructures are now beginning to overcome these limitations, creating a timely opportunity to explicitly incorporate microbial processes into climate models. Therefore, integrating accurate microbial functional traits and community responses to stressors into climate projections will refine forecasts of carbon-cycle feedbacks, tipping points, and ecosystem thresholds.

1.4. From fragmentation to integration

The WMP unites human, animal, plant, and environmental microbiome initiatives under a shared "One Health and Planetary Health" vision [6]. Within it, the Environmental & Climate Change (WMP-ECC) Working Group focuses on closing critical gaps between microbial science and climate action.

Our newly launched Roadmap on Microbiomes and Climate (2025–2027) (Fig. 1), presented at the WMP inaugural summit in Paris in June 2025, is structured around three scientific priorities that define what is currently missing from climate mitigation, adaptation, and rehabilitation efforts: (i) microbial process accounting, (ii) global integration of microbiome data, and (iii) microbiomes to enhance ecological resilience. These priorities are implemented through four pillars that provide the technical, institutional, and governance mechanisms required to translate microbial knowledge into policy-relevant action: (i) integrating microbial data into Earth system and risk models, (ii) developing microbially informed standards for ecosystem rehabilitation and regenerative practices, (iii) advancing equitable governance and benefit sharing for microbial resources, and (iv) building capacity, and open data platforms, particularly in under resourced regions.

The Roadmap outlines how existing data infrastructures can be connected and harmonised to inform climate action. The goal is to move from fragmentation to interoperability, to make microbial knowledge actionable for mitigation and adaptation across continents, regions and disciplines.

2. Three priorities for a microbial climate agenda

The WMP-ECC Roadmap highlights three foundational priorities that bridge science, technology, and equity.

2.1. Recognition of microbial processes in global accounting

Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC) mechanisms should explicitly include microbial transformations in greenhouse gas inventories and carbon budgets across terrestrial, freshwater, and marine systems. This must also encompass agricultural and forestry microbiomes, which underpin soil fertility, nutrient cycling and crop productivity, collectively accounting for nearly one-third of global greenhouse gas emissions. Microbial indicators can improve traceability and reduce uncertainty in nature-based solutions (NbS) and carbon-offset schemes, particularly in soil-carbon and agro-ecosystem management. Integrating microbial functional data into global accounting will refine climate projections and reveal hidden feedbacks between ecosystem processes and greenhouse-gas fluxes, and inform more sustainable agri-food, ocean and land-use policies aligned with the goals of both Working group D (Food Systems Microbiomes) and the WMP-ECC Roadmap.

2.2. Enhance interoperability and equity across microbial observation efforts

Rather than establishing a new monitoring framework, the WMP calls for linking and enhancing existing networks, from marine time-series and soil observatories to atmospheric microbiome initiatives through shared standards, metadata harmonisation, and open data interfaces. Strengthening interoperability among these efforts will enable microbial community and biogeochemical datasets to inform climate modelling and policy in a consistent way.

At the same time, emerging live single-cell metabolic profiling and sorting technologies (*e.g.*, the Ramanomics platform [7], *in situ* DNA extraction and community profiling [8]) can vastly improve our ability to detect, monitor, cultivate, and apply functional microbes for restoring or improving ecosystem function directly *in situ*. Integrating such innovations within existing infrastructures will accelerate the translation of microbial data into actionable insights plus deployable solutions such as microbial products that can bring economical benefits to local communities.

To ensure equity, participation from the Global South, where microbial diversity and vulnerability are greatest but underexplored [9,10], must be embedded from the outset and governed under the CARE principles (Collective Benefit, Authority to Control, Responsibility, Ethics [11]).

2.3. Integration of microbiomes into rehabilitation and NbS portfolios

The success of blue-carbon, soil-carbon, and rewilding initiatives depends on microbial interactions that regulate productivity, stability, and resilience. Managing these microbiomes by recognizing and rehabilitating symbiotic networks, protecting viral-microbial balance, or reducing disturbances can enhance both carbon retention and ecological resilience. Coupling rehabilitation with technology-enabled microbial cultivation and application can also generate tangible socioeconomic benefits, reinforcing both ecosystem and community resilience [12].

3. Equity, capacity, and the just transition

Microbiome science must not reproduce existing global asymmetries in data ownership, infrastructure, and decision-making. Equity,

Fig. 1. The WMP call to action and its three priorities for a microbiome-inclusive future. Microbiomes, depicted as hands, support the Earth in raising awareness of the essential role of microbiomes in achieving a sustainable future. The Earth's microbial future © 2025 by Giulia Ghisleni is licensed under CC BY-SA 4.0.

capacity building, and the just transition are therefore embedded across all priorities of the Roadmap. North-South and South-South initiatives can demonstrate how distributed sequencing, functional monitoring, and citizen science can empower equitable participation and local ownership of microbial data [13]. The recent International Union for Conservation of Nature (IUCN) initiative to protect microbiome diversity [14] represents a landmark step in aligning microbial stewardship with global biodiversity governance, signalling that the conservation of microbial life is integral to planetary health and justice. Embedding such frameworks into climate and biodiversity policy can ensure that microbial observation, rehabilitation, and benefit-sharing are pursued as genuinely inclusive and co-created processes with indigenous and local knowledge systems.

4. Toward COP30 and beyond

COP30 represents a turning point: the Global Stock take under the Paris Agreement seeks to align mitigation and adaptation with science-based evidence. Microbial data from soil respiration potential to planktonic carbon export, offer unprecedented, high-resolution measures of ecosystem function that directly support the three priorities outlined in this text.

We urge governments, funding bodies, and multilateral organisations to:

- Embed microbial processes within UNFCCC, Convention on Biological Diversity (CBD), and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) frameworks.
- Strengthen coordination and interoperability among existing and future microbiome observatories under the WMP umbrella and within the One Health framework.
- Incorporate microbial indicators into Nationally Determined Contributions (NDCs) and Loss-and-Damage assessments.
- Invest in platform-building, technology-innovation, and data-sharing mechanisms that recognize microbial knowledge and microbiota-derived resources as part of global climate infrastructure.

5. A call to action

Microbes are the planet's smallest engineers, but its largest collective force. Neglecting them weakens every model, projection, and rehabilitation plan. Recognizing and exploring microbial processes in global governance is therefore not symbolic; it is essential for robust mitigation, adaptation, and ecosystem rehabilitation.

We call for the coordination of terrestrial, freshwater, and ocean microbiome observatories into a shared, interoperable infrastructure that enables data comparability, functional synthesis, and equitable participation across regions and countries. This framework must link functional, genomic, phenotypic, and environmental data streams, allowing microbial processes to be embedded directly into Earth-System models, biodiversity indicators, and decision-support tools.

In partnership with major international data infrastructures and analytical platforms, our working group aims to coordinate the exploitation of one of the largest ocean molecular datasets [15] through two complimentary implementation pathways. First, integrated multi-omics will enable consistent functional interpretation across environments and scales. Second, systematic intercomparison of analytical pipelines, including agreements, disagreements, and uncertainty ranges will establish transparent benchmarks for reproducibility and fitness for purpose across regions, technologies, and infrastructures.

Emerging collaborative initiatives including iMAPS (http://iMAPS.info), Text Retrieval Conference (TREC) [16], Mission Microbiomes [17], and Tara Oceans [18] demonstrate the feasibility and scientific value of harmonised, function-first microbiome observations. Building on these efforts, we propose that each environmental sample contributes to a multi-dimensional "**6 W**" dataset: **What** (function), **Who** (genome), **Why** (expression and regulation), **When** and **Where** (contextual metadata), and **Wealth** (living collections and cultivable diversity).

Such multi-modal datasets form a practical foundation for ecosystem rehabilitation, early-warning indicators, and sustainable bio-innovation, while enabling regional ownership of data generation and interpretation. By empowering microbiome science across soils, crops, animals, rivers, and oceans, this coordinated approach can accelerate climate action while ensuring equitable access to microbiome-derived benefits.

6. Governance and coordination

We propose a federated governance model in which microbiome data and decision-making remain regionally stewarded, while

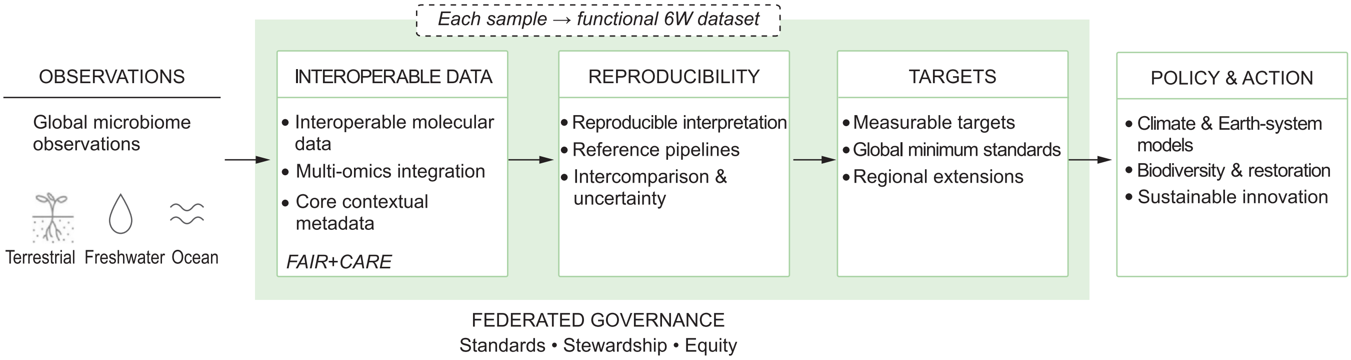

Fig. 2. From microbiome observations to policy-relevant action. Distributed microbiome observations across terrestrial, freshwater, and ocean systems feed into interoperable molecular data integrating multi-omics and contextual metadata. Reproducible interpretation is ensured through reference pipelines and systematic intercomparison. A federated governance framework (local data ownership with global coordination of standards and methods) supports measurable global targets with regionally adapted extensions, translating microbiome data into policy-relevant indicators for climate action, biodiversity conservation, food security and ecosystem rehabilitation.

interoperability, standards, and analytical benchmarking are coordinated globally. Shared oversight mechanisms support harmonised metadata, reference pipelines, and systematic intercomparison, enabling reproducible interpretation across biomes and regions. Governance is anchored in FAIR (Findable, Accessible, Interoperable, Reusable) and CARE principles to ensure data sovereignty, equitable participation, and benefit sharing, with capacity building embedded as core infrastructure rather than an auxiliary activity (Fig. 2).

The WMP Environment and Climate Change Roadmap provides a blueprint for action, embedding microbial systems into climate science and governance by aligning three scientific priorities with four implementation pillars that enable data interoperability, federated governance mechanisms, and measurable microbial targets. Building an interoperable, governed, and inclusive global microbiome infrastructure is both a scientific and ethical imperative. To mitigate climate impacts and rehabilitate the ecosystem, we must rehabilitate, preserve and connect the microbiome that sustains them.

CRediT authorship contribution statement

Emma Rocke: Writing – review & editing, Writing – original draft, Conceptualization. **Rob Knight:** Writing – review & editing, Conceptualization. **Guilia Ghisleni:** Writing – review & editing, Visualization, Conceptualization. **Tim McAllister:** Validation, Writing – review & editing. **Alice Ortmann:** Conceptualization, Validation, Writing – review & editing. **Antonia Bruno:** Conceptualization, Validation, Writing – review & editing. **Jimenez Diego:** Conceptualization, Validation, Writing – review & editing. **Jian Xu:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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