

REVIEW ARTICLE

Exiting the Anthropocene: Achieving personal and planetary health in the 21st century

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Abstract

Planetary health provides a perspective of ecological interdependence that connects the health and vitality of individuals, communities, and Earth's natural systems. It includes the social, political, and economic ecosystems that influence both individuals and whole societies. In an era of interconnected grand challenges threatening health of all systems at all scales, planetary health provides a framework for cross-sectoral collaboration and unified systems approaches to solutions. The field of allergy is at the forefront of these efforts. Allergic conditions are a sentinel measure of environmental impact on human health in early life—illuminating how ecological changes affect immune development and predispose to a wider range of inflammatory non-communicable diseases (NCDs). This shows how adverse macroscale ecology in the Anthropocene penetrates to the molecular level of personal and microscale ecology, including the microbial systems at the foundations of all ecosystems. It provides the basis for more integrated efforts to address widespread environmental degradation and adverse effects of maladaptive urbanization, food systems, lifestyle behaviors,

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and socioeconomic disadvantage. Nature-based solutions and efforts to improve nature-relatedness are crucial for restoring symbiosis, balance, and mutualism in every sense, recognizing that both personal lifestyle choices and collective structural actions are needed in tandem. Ultimately, meaningful ecological approaches will depend on placing greater emphasis on psychological and cultural dimensions such as mindfulness, values, and moral wisdom to ensure a sustainable and resilient future.

KEYWORDS

biodiversity hypothesis, climate change, nature-relatedness, noncommunicable diseases (NCDs), planetary health

1 | INTRODUCTION

Humans are part of nature, and our health cannot be separated from the health of our environment. Fully understanding ecological interdependence is to see personal health as part of planetary health. The rising rates of human disease, distress, and despair are inextricably linked with degradation and destruction of ecosystems at all scales. This extends to the human-made social, political, and economic “ecosystems” that influence attitudes, values, and behaviors—of individuals and whole societies.^{1–4} We cannot hope to overcome the pandemic of chronic, noncommunicable diseases (NCDs), as an expression of these deepening imbalances, without addressing the wider determinants of health that penetrate down to the molecular level. This underscores the importance of understanding the intricate connections between the biological, psychological, social, and cultural aspects of health in the contemporary environment. The COVID-19 pandemic has further highlighted the interdependence of all systems, and how the pre-existing NCD pandemic magnified unequal vulnerability to acute this threat.⁵

Indeed, researchers in the field of allergy were among the first to identify links between environmental ecology, including biodiversity loss, and the rising predisposition to immune disease, as discussed further below.^{6–9} This insight increased awareness that the ecology of the early environment—including microbial diversity, nutrition, nature, social interactions, and the totality of exposures in the wider “exposome”¹⁰—have life-long implications for immune system development, and in turn, all aspects of health and resilience.

The concept of planetary health provides a framework to increase awareness of how the health of individuals, communities, and the Earth's natural systems are interdependent, and for the level of cross-sectoral discourse and collaboration required to address these challenges^{1–4} (Figure 1). Planetary health illuminates pathways through which adverse changes in macroscale ecology—of food systems, lifestyle behaviors, socioeconomic disadvantage, and environmental degradation—all impact personal ecology, including the microbial systems at the foundations of all ecosystems. Of immediate relevance, changes in the function and composition of the human-associated microbiome are directly implicated in the mounting global burden of NCDs, through immune

and metabolic dysregulation across the lifespan. This collective adverse shift in ecology at all scales has been described as “dysbiotic drift”,¹¹ and underscores the need for ecological approaches aimed at restoring balance, symbiosis, mutualism, and sacred reciprocity. In particular, as foundational ecosystems, microbiome science has provided clear evidence of links between biodiversity and health of all systems, from climate systems to the health of each individual living organism.¹²

We equally recognize that the “bonds between humans, spirit and nature” and the inter-connectedness of all life¹³ are foundational within Indigenous land-based worldviews.¹⁴ Indigenous traditional knowledges have long recognized that interference with the balance of natural systems and rhythms directly impacts human wellbeing—a perspective that encompasses the living energy of nature, with spiritual rather than just materialistic value.¹⁵ This relational world view is at odds with the primarily “transactional” nature of dominant western culture. Including these deep and intentional reciprocal relationships with nature, that have been undervalued and even undermined by most modern societies, is an important dimension of the planetary health agenda.^{14,15}

In this article, we underscore the need for multisectoral strategies and deep structural change—guided by principles of planetary health that recognize the interdependence of all systems. We describe a far more comprehensive “exposome” (total lived experience across time) approach that balances reductionism with holism.¹⁶ No matter how innovative, a targeted “downstream” focus on disease will ultimately fail if not considered along with the “upstream” lived experience, which differentially shapes the health of (marginalized) people and communities over time.¹⁷ Taking a wider exposome approach gives greater focus to upstream factors implicated in dysbiosis. This includes food systems, nature-relatedness, built environments, the health of wider environments, and the policies and practices which can facilitate or inhibit dysbiotic drift.¹¹ Finally, we underscore why meaningful change will equally depend on addressing the underlying value systems and worldviews that created and perpetuate our global challenges.¹⁸ The 2022 Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) describes this as “inner transformation towards sustainability,” addressing values, and individual and collective mindsets through

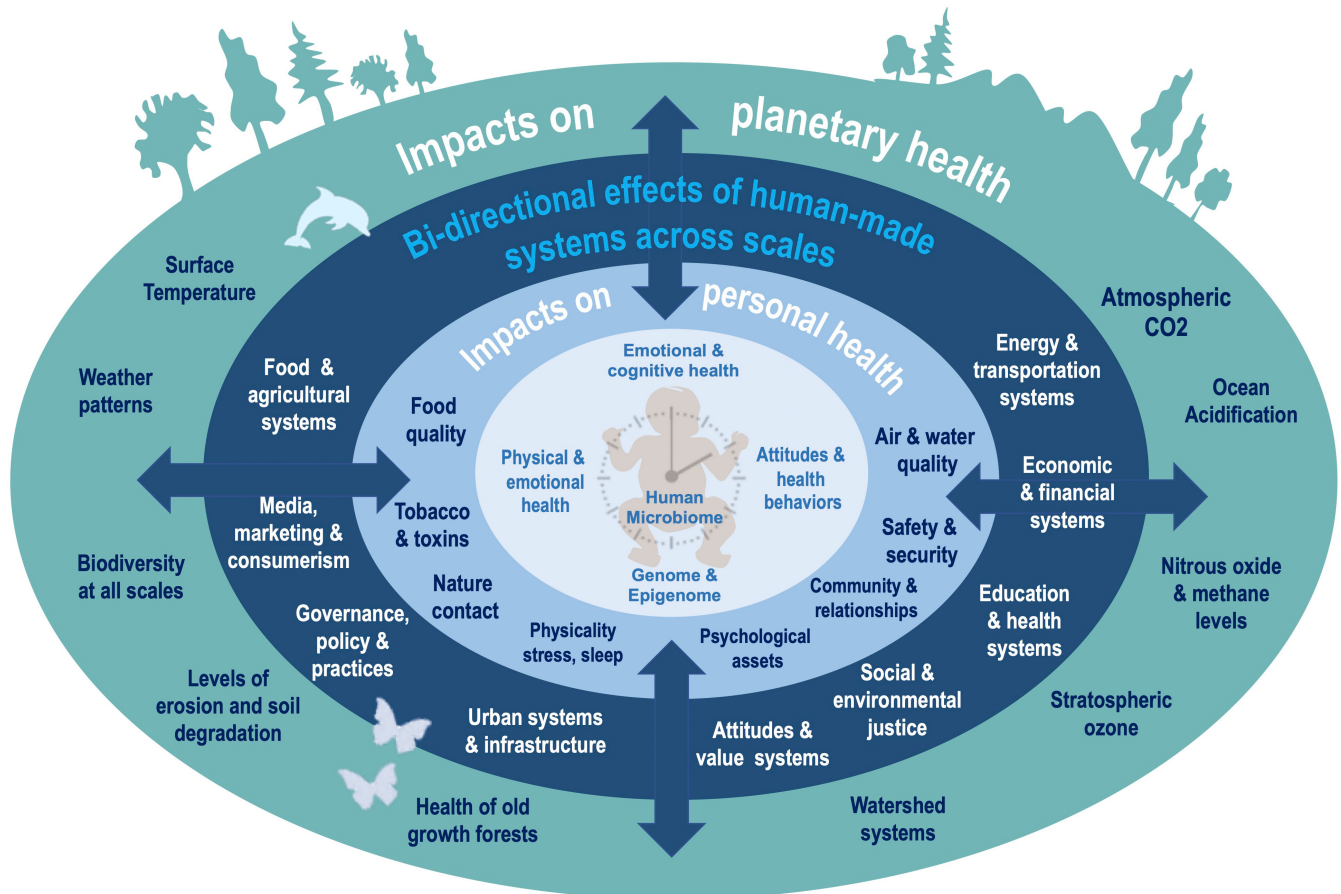


FIGURE 1 Health of people, places, and planet are interconnected: An integrated planetary perspective recognizes and addresses the interconnected bi-directional influences that can either promote or undermine resilience and the capacity for flourishing at all scales. Human-made systems, structures, attitudes, and values (dark blue) have a profound effect on local, proximal environments that influence personal health to the molecular scale from the first moments of life (inner circles), as well as the health of wider planetary systems upon which all life depends (outer circle). This underscores the need for more mutualistic, integrated cross-sectoral strategies that address the policies and practices (and the attitudes and values that govern these) for solutions that provide co-benefits for individuals, communities, and the natural systems, we are part of (Diagram created by author S.L.P)

nature connection, “meditation, yoga or other social practices” and the propagation of a wiser “sustainability culture”.¹⁹

Our purpose is not to provide a sector-focused review of all systems and structures that contribute to planetary health or undermine it, as that has been covered elsewhere (including the wide-ranging biophysical systems, social, cultural, and economic systems).^{1,20} Rather, we aim to underscore the interdependence of these systems, and the importance of integrated approaches that provide more comprehensive solutions with co-benefits, than those that can be created in isolation with siloed approaches.

2 | ALLERGY: AT THE FOREFRONT OF MODERN CONCEPTS OF PLANETARY HEALTH

In the 1960's, notions of altered “balance” and reciprocal links between environmental ecology and human health, particularly immune health, emerged in modern medical discourse. Weeks before

the 1969 Moon landing, Pulitzer-prize winning microbiologist Rene Dubos (1901–1982) gave a keynote presentation entitled “The Spaceship Earth” at the annual meeting of the American Academy of Allergy (now the American Academy of Allergy, Asthma and Immunology).⁶ Already, the “Earthrise” photograph, taken on the 1968 Apollo 8 mission had begun to trigger a profound shift in environmental awareness and desire for human unity, which would inspire the first Earth Day in 1970, and give rise to large-scale social and environmental movements.²¹ Dubos proposed that allergy could be considered a sentinel measure of planetary health—altered immune “reactivity” that reflects the state of the world around us. Dubos was among the first to identify the ways in which formerly unseen microbes illuminate the interrelated economy of natural systems, and “give to the phenomenon of symbiosis a significance which transcends analytical biology and reaches into the very philosophy of life”.²² Decades before the hygiene hypothesis gained popularity, he warned of the long-term implications of antibiotic overuse and sanitization, environmental degradation, and biodiversity loss on all aspects of health—particularly in children. He even predicted a

pandemic of physical and mental disease as a delayed consequence of massive urbanization, unhealthy lifestyles, and environmental stress that would take generations to fully manifest.¹⁰

In arguing that this rapid, large-scale human activity was damaging to the health of people, places (ecosystems), and the planet, Dubos suggested this could place the allergy profession at the center of transdisciplinary discourse. He encouraged the profession to look beyond the narrow disease-oriented definition of allergy and consider a larger view—one that connects the allergy and immunology profession to virtually all branches of medicine, as well as the social, psychological, anthropological, and environmental tributaries of science. He concluded his talk by calling for a NASA moon-shot-like effort “for the study and control of forces that affect the quality of human life and its environment, and that are rapidly making the Spaceship Earth a place unfit for human life”.⁶

Since then, researchers in the allergy field have been at the forefront of discoveries documenting environmental impacts on the developing immune system and the risk of inflammatory disease—including changing diet and lifestyle patterns, modern environmental toxins, and urbanization, declining contact with natural environments, and numerous social factors (reviewed in¹⁰). Advances in technology illuminated pathways through which these factors mediate developmental effects, most notably through the gut microbiome. This deepened the understanding of connections between microbial ecology and wider ecosystems and expanded initial concepts of the “hygiene hypothesis” to encompass a broader “biodiversity hypothesis”.^{9,23,24} Furthermore, groundbreaking notions of the “epithelial barrier hypothesis” now add another inter-related dimension to how ubiquitous environmental toxins mediate adverse biological effects. This proposes that toxins (such as detergents, enzymes and emulsifiers in ultraprocessed food,²⁵ microplastic, nanoparticles, household cleaners, ozone, and air pollution) disrupt epithelial barrier integrity—increasing the systemic effects of microbial dysbiosis that, in turn, lead to a multitude of inflammatory diseases.^{26,27} It has also been proposed that other modern exposures (such as increased advanced glycation end-products in Western diets) mimic natural alarmins, providing “false alarms” that active innate immune responses to increase risk of inflammatory NCDs.²⁸

There is no longer any doubt that many alterations in ecological “balance” have contributed to the epidemic rise in allergic disease from the second half of the 20th century, as part of the vast collective rise in NCDs over the same period. These multifaceted modern environmental interactions operating in concert illustrate the interconnectedness of planetary health. While technological advances continue to provide new dimensions to the complex interdependent interactions of the exposome, the very nature of these ecological challenges calls for more integrative approaches with more collaborative, mutualistic vision.^{14,29}

Here, in this context of planetary health, we explore the ways in which the allergy field continues to inform our understanding of the bi-directional relationships between the health of people, places, and planet (with major milestones in planetary health awareness

described in Table 1). We anchor our discussion with emerging microbiome and exposome science—as key mediators of immune health. Furthermore, we use the lens of Dubos, approaching allergy in its broadest definition of altered immune “reactivity,” to query the ways in which the concept of planetary health can shape perspectives in allergy research and practice, and how this in turn can contribute to addressing the grand challenges of our time.

3 | PLANETARY HEALTH: UNDERSCORING THE INTERDEPENDENCE OF ALL SYSTEMS

Planetary health spans far more than climate change and biodiversity loss. It has been defined as the interdependent vitality of all natural and anthropogenic ecosystems (social, political and otherwise),⁴ underscoring that the health of humanity cannot be uncoupled from the natural systems within the Earth's biosphere.¹ The concept of planetary health is intended to erase the artificial lines that often silo health at scales of “people” (so called “individuals”), “places” (local environments and communities), and “planet.” As such, it encompasses the range between large-scale global systems and the sub-cellular dynamics within each living organism. It also seeks to integrate the biological, psychological, social, cultural and environmental aspects of health in the Anthropocene, and the urgent need to address these collectively across every level.³⁰

The concept of planetary health is intended to encompass and examine the many grand challenges of our time, and develop science-informed solutions to the pressing problems of “Anthropocene Syndrome”—the many interdependent issues of late modernity including the NCD pandemic and mental health crises; over-consumption/materialism and spread of ultra-processed foods; growing income disparities, poverty, and health inequalities; environmental degradation, climate change, and so many other associated problems.^{31,32} Lancet Editor-in-Chief Richard Horton, one of the architects of the Lancet Commission on Planetary Health,¹ describes planetary health this way: *Planetary health, at least in its original conception, was not meant to be a recalibrated version of environmental health, as important as environmental health is to planetary health studies. Planetary health was intended as an inquiry into our total world. The unity of life and the forces that shape those lives*.³³

Thus, the notion of planetary health is antithetical to the siloed ways in which the sciences of health and medicine often operate; as a transdisciplinary effort, it challenges scientists in diverse fields—no matter how reductionist the scope of their inquiry—to see the large-scale relevancy of their work. At the same time, it challenges healthcare providers to move beyond the disease model toward a broader vision of human flourishing (Figure 2) wherein individuals are considered as living embodiments of accumulated experiences shaped by natural and anthropogenic (i.e., social, political, commercial) ecosystems.^{34,35} Indeed, a “planetary health pledge” was recently published in the Lancet, with the goal of uniting health professionals around these issues in the Anthropocene, while emphasizing the connection between health

TABLE 1 Major milestones: concepts of planetary health in the Anthropocene

1960's	Growing global environmental movements and planetary consciousness (magnified by NASA's Apollo 11 "Earthrise" photograph in 1968) culminate in the first "Earth Day" in 1970 ⁴⁴ ; first predictions that environmental degradation, and biodiversity loss (including "indigenous microbiota" with antibiotic overuse) would have long term, intergeneration effects on human physical and mental health ⁴⁵ —but remained largely overlooked.
1970's	Early calls for more integrated research and practice in a framework that recognizes the connections between "individual, community, environmental and planetary health". ⁴⁶ Expansion of more integrated, holistic approaches to human and environmental health—remains largely outside the "mainstream" discourse.
1980's	Greater acknowledgement that these ideas have been deeply embedded within Indigenous knowledges for centuries—"to harm the Earth is to harm the self". ⁴⁷ Environmental group, Friends of the Earth, expands the World Health Organization definition of health to include ecological and planetary health views: "health is a state of complete physical, mental, social and ecological well-being and not merely the absence of disease — that personal health involves planetary health". ⁴⁸
1990's	Expanding calls for a "planetary view" that recognizes interconnectedness of all life and that connection to nature is essential to human physical, emotional, and spiritual well-being. ^{13,49,50} In 1997, our co-author, public health physician Dr. Trevor Hancock articulated the need to "talk about planetary health as the ultimate determinant" of human development. ⁵¹
2000's	First proposed use of the term "Anthropocene" to describe large-scale impact of human activity on planetary systems ⁵² ; followed by evolving conceptual and historical perspectives ⁵³ ; Developing models and discussions of "planetary boundaries" and a safe operating space for humanity ⁵⁴
2010's	White paper from the Global Health Summit (Beijing, China, 2013) articulates the future of well-being lies in concepts and policies of planetary health, ⁵⁵ subsequently articulated in the Lancet in 2014, ⁵⁶ with 2015 launch of The Rockefeller Foundation-Lancet Commission on planetary health "Safeguarding human health in the Anthropocene epoch" ¹ ; in face of "great acceleration" of planetary health boundaries ⁵⁷ ; establishment of the Planetary Health Alliance and creation of the Lancet Planetary Health journal (2017).
2020's	Significant growth and widespread interdisciplinary, cross-sectoral engagement in planetary health initiatives; planetary health conferences; the Sao Paulo Declaration on Planetary Health ⁵⁸ ; creation of the "Planetary Health Pledge", ³ and numerous other activities and collaborations.

at the "personal" and "planetary" scales.³ This interprofessional pledge emphasizes that "do no harm" includes harm to the Earth and underscores the necessity to safeguard the health of present and future generations and promote intergenerational and intra-generational equity and justice.³

With this planetary health lens, we can also see healthcare in a more fulsome way, that encourages us to consider the interplay between the ecology of each individual and their environment. This has been bought more sharply into focus with the emergence of microbiome science (discussed below), which now considers each patient in the "waiting room" as a multi-species entity with a microbial cell to match each human cell. The understanding that many microbes are "functional" (producing metabolites with benefits for their host), highlights their potential to influence many aspects of personal health, even behavior and mental outlook.^{36,37} In turn, it has become clear that microbiomes are individualized and reflect both personal behavior and the wider environment mirroring their total lived experience over time—essentially the biopsychosocial manifestation of life in the Anthropocene.³⁸

Planetary systems comprise countless smaller scale systems, that, while interconnected and interdependent, remain unique in their local context. Thus, just as "personalized medicine" recognizes the unique influence of the exposome on individuals, each environmental ecosystem has unique signatures and conditions that have been differentially affected by human activity. This also underscores the importance of local solutions for local communities, including biocultural diversity and environmental justice for poor and marginalized people—often excluded from the dominant social discourses in an era of globalization referred to as "the era of marginalization of the majority" by Argentinean philosopher Enrique Dussel.³⁹

To this end, Figure 3 provides a local example from a South American Indigenous community, the *Pewenche*—who define themselves as people (= *che*) of the Monkey-Puzzle tree (= *Pewen*) on the volcanic Andean mountains. Medical science now provides a modern functional perspective of the traditional knowledge, spirituality, and social practices centered around gathering *Pewen* seeds, showing how the *Pewenche* worldview converges with an ecobiogeochemical perspective of the sulfur cycle. In short, volcanic



FIGURE 2 Laudable goal—flourishing as more than the absence of disease: Equitable flourishing and fulfillment of individuals requires societies, systems, and values that promote mutual flourishing. It also depends on overcoming the systemic factors that undermine this, recognizing the interconnected ways these influence the wellbeing of people, places, and planet. (Original figure, reproduced from Logan et al. *Int. J. Environ. Res. Public Health* 2021, 18, 12,788, with author's permission. Copyright by the Author S.L.P.)

ash (hydrogen sulfide and sulfur dioxide) transmitted to soils through wind and water is transformed to sulfate by soil bacteria and fungi, then absorbed by the roots of the *Pewen* tree. Metabolized by the tree to sulfur-containing essential amino acids methionine and cysteine, the *Pewen* seeds provide critical dietary nutrients for the health of the *Pewenche*.⁴⁰ Like so many ecological niches, this balanced health cycle and watershed region has been under threat by the construction of dams that would flood the *Pewen* forests. The adverse consequences for the *Pewenche* span from the molecular level to their deep spiritual connection with the land.

This is but one microcosm of the innumerable delicate systems that exist on this planet. There are also now countless examples of forced dislocation or destruction of traditional Indigenous lands, and loss of access to traditional foods. The detrimental effects on health, particularly for Indigenous Peoples, include higher rates of inflammation, diabetes, and NCDs,^{41,42} likely reflecting alteration in underlying microbiome health.^{29,43} In essence, the effects of Western “colonization” (forced and imposed ways of thinking, believing, acting) are disrupting health at the molecular level—in *all* populations experiencing dysbiotic drift.

Therefore, planetary health calls for holistic integration of habitats and habits, ecosystems, and cultures in ways that, akin to personalized medicine and an individual's unique exposome, recognize (and respect) both the specificity of each situational challenge and how it is connected to (and enriches) the wider global systems.

4 | THE MICROBIOME AS A MEDIATOR AND A MEASURE OF UNHEALTHY SYSTEMS

In many ways, microbiome science has served to illuminate the unseen or otherwise ignored links between health at personal, public, and planetary scales—in tangible and measurable ways. For example, in addition to over-prescription of antibiotics,⁵⁹ many other factors such as air pollution,⁶⁰ environmental toxins,⁶¹ psychological stress,^{62,63} ultra-processed food⁶⁴ and dietary advanced glycation end-products (AGEs),⁶⁵ emulsifiers,⁶⁶ phthalates⁶⁷, sleep disruption,⁶⁸ tobacco use,⁶⁹ sedentary behavior,⁷⁰ and excess alcohol consumption,⁷¹ have been shown to impact the microbiome. Again, many of these factors disproportionately affect marginalized populations, often simultaneously. Indeed, recent studies have linked socioeconomic disadvantage to reduced diversity of oral and stool microbiota as a likely pathway to a far greater burden of immune-metabolic dysregulation and NCDs.^{72–76}

This is magnified by deficiency, loss, or displacement of protective or buffering environmental factors that favor healthy microbiomes—such as dietary phytochemicals, fiber, omega-3 fatty acids, vitamin D, and other nutrients.⁷⁷ Experts in allergy and other fields have elucidated mechanisms and pathways by which these and other microbiome-altering factors can disturb barrier function (e.g., intestinal, skin, lung, and/or blood–brain), provoke low-grade systemic inflammation, add to allostatic load, and ultimately increase the risk of NCDs.^{27,78}

Thus, the concept of “dysbiotic drift” with progressive westernization reflects how both an increase of detrimental factors and a decline of beneficial factors adversely impact the human microbiome.¹¹ While many of these have been considered “lifestyle” factors—implying personal blame for easily modifiable choices—this overlooks the unequal opportunities, pervasive marketing, structural barriers, and excessive burden in marginalized communities, where the total lived environment has greater potential to push dysbiosis and inflammation by default.⁷⁹ Socioeconomic disadvantage is associated with increased risk of psychological distress, circadian disruptions, lower availability of fresh produce coincident with higher concentration of convenience stores and fast-food outlets, greater airborne particulate matter, targeted marketing of unhealthy products, aircraft/road/industrial noise, and diminished access to safe parks/greenspace.⁸⁰ Discrimination and racism also predict low-grade systemic inflammation,^{81,82} and even brief laboratory provocation of mere *feelings* of poverty, discrimination and/or ostracization is enough to push dietary choices in an unhealthy direction.^{83,84}

In addition to unequal burden of *chronic* disease, the COVID-19 pandemic has revealed vast inequalities in vulnerability to *acute* threats. In westernized countries, the burden of the pandemic has been clearly shouldered by marginalized and socioeconomically disadvantaged individuals and communities, with higher co-morbid NCDs as a major risk factor for COVID-19 severity and mortality.⁸⁵ The emerging perspective of the microbiome as a “transducer” of adverse external ecosystems (extending to the social, economic,

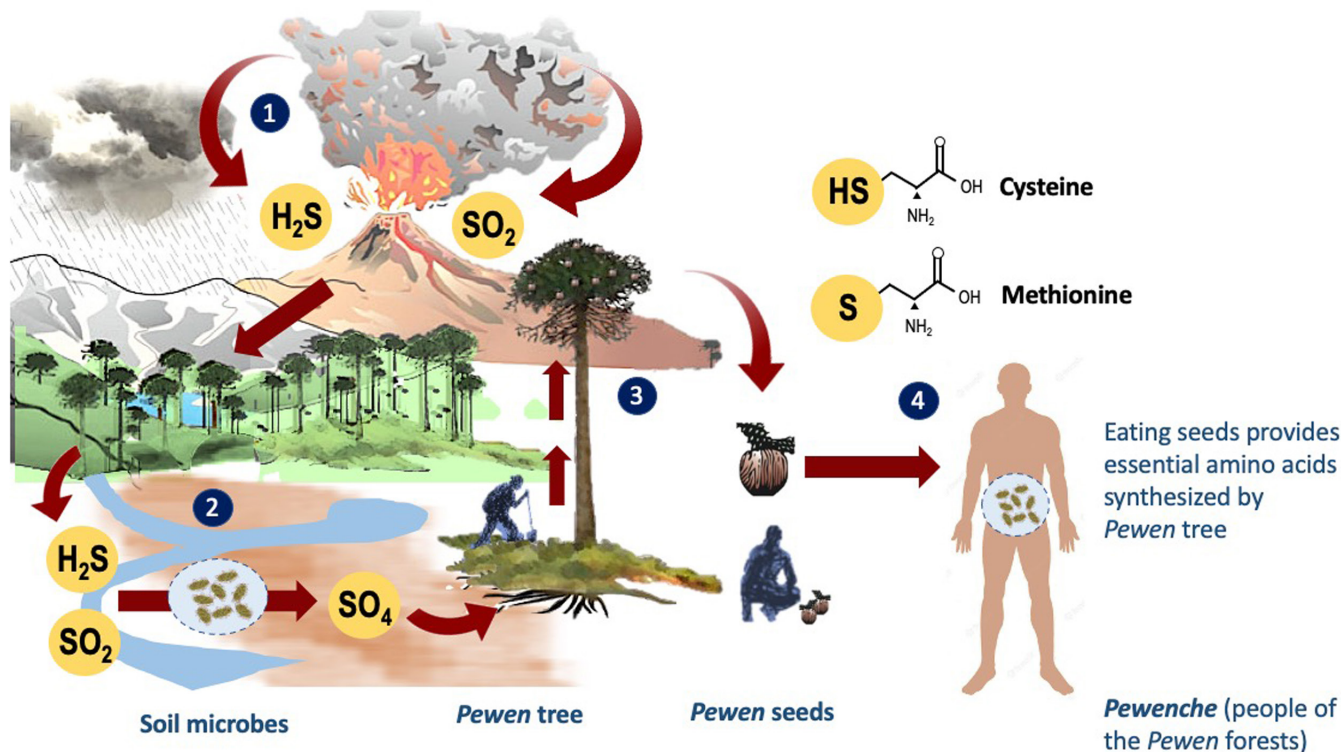


FIGURE 3 Traditional knowledges of the *Pewenche* Indigenous community converge with an eco-biogeochemical perspective of the sulfur cycle in forest habitats: Sulfur from the volcanoes and their ash is transported by wind and water (1) and reaches soils (2) where bacteria and fungi transform hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) into sulfate (SO_4) through processes of oxidation and reduction, which can be absorbed by the roots of the *Pewen* (Monkey-Puzzle) tree. In a series of enzymic reactions, the tree assimilates sulfur (3) from the inorganic sulfate molecules to synthesize organic molecules that generate the two essential sulfur-containing amino acids methionine and cysteine. The seeds are ingested by the *Pewenche* community, providing essential amino acids. The *Pewenche*, people (=che) of the trees (=Pewen) are part of the larger *Mapuche* community who define themselves as people (=che) of the land (=mapu). In accordance with traditional knowledge, when they eat the seeds with the amino acids synthesized by the tree (*Pewen*), they are also eating the sulfur of the volcanic land (*Mapu*). Figure adapted from Rozzi, R., *Biocultural Ethics: From Biocultural Homogenization Toward Biocultural Conservation*. In *Linking Ecology and Ethics for a Changing World: Values, Philosophy, and Action, Ecology and Ethics*, Rozzi, R. E., May Jr, Roy H. (Editor), Chapin III, F. Stuart (Editor), Ed. Springer, Dordrecht: 2013. (Copyright by the Author R.R)

political, commercial forces that govern these) on internal ecosystems, has suggested that this may be a key pathway of immune compromise in the context of unequal susceptibility to the effects of COVID-19.^{86–89}

5 | THE NEW FRONTIER OF EXPOSOME SCIENCE: NEW AVENUES FOR MAKING CONNECTIONS FOR INTEGRATED SOLUTIONS

Noncommunicable diseases are common, complex, multifactorial diseases. While genetic predisposition plays a role, the global surge in diseases can only be explained by complex environmental changes, as experts in allergy have shown for decades. One of the primary scientific challenges has been untangling a) complex interactions, b) direction of effects, and c) level of causation of myriad associations with disease vs. flourishing—which cannot be understood by reductionist one-variable-at-a-time approaches. In the context of

personalized medicine, exposome science provides a new frontier to address this, aided by advances in “omics” technology that allows large-scale analysis of functional proteins (proteomics), metabolites (metabolomics), gene expression (epigenomics, transcriptomics), and genetic influences on specific drugs or nutrients (pharmacogenomics). Exposome science seeks to examine total accumulated environmental exposures (both detrimental and beneficial) and tease them apart to help predict the biological responses of the “total organism to the total environment”⁹⁰ over time.⁹¹ While not yet implemented widely, application of exposome science to personalized medicine holds much promise for the future.

However, the value of exposome science also extends to the heart of planetary health—allowing for analysis of previously undetected factors with the potential to act as health assets in living environments and/or potentially detrimental factors that influence human psychobiology.⁹² Since exposome science can combine internal (e.g., human biospecimens and physiological markers) and external (e.g., chemical, physical, psychological, neighborhood, food systems, and social factors) measurements in a temporal way, there

is enormous potential for advances in our understanding of the interwoven complexities and multiscale nature of planetary health.⁹³

In the context of grand challenges, where pandemics of NCDs and infectious disease are intersecting with climate change and other wicked problems, exposome science can help inform policies and practices aimed at promoting human flourishing with biodiversity and sustainability in mind⁹⁴ (see Table 2 for future directions).

6 | NATURE-BASED SOLUTIONS: TANGIBLE ACTIONS WITH CO-BENEFITS FOR PEOPLE, PLACES, AND PLANET

Nature-based solutions provide practical, tangible ways for individuals and groups to make a meaningful difference to both their

TABLE 2 Future research directions

- Increase efforts to discover and invest in solutions with multiple co-benefits for people, places, and planet—for example, regenerative (“no till”) agriculture that may restore soil (microbial) health, reduces erosion and water pollution, produces more nutritious food for human health, and sequesters atmospheric carbon dioxide to help reverse climate change.
- Define, understand, and utilize the many bi-directional pathways linking macro-scale systems (including physical, structural, and social systems) and microscale systems (including microbial, cellular systems) for novel solutions.
- Expand focus on nature-based solutions, green infrastructure, more local produce and fresh foods, focus on restoring positive assets—both human assets (e.g., physical and emotional) and environmental assets (e.g., biodiversity)—that have been eroded in the Anthropocene.
- Expand the bio-psycho-social paradigm to discover pathways that will help unmask, evaluate, and address the biological consequences of socio-economic inequalities.
- Undertake more research into how NCDs create greater vulnerabilities to infectious disease (e.g., COVID-19) and other new threats including, but not limited to, climate change.
- Greater efforts to understand and address the attitudes, values, behaviors, and ideologies (of individuals and groups) that created and perpetuate the Anthropocene. This includes strategies to co-create more mutually beneficial sustainable worldviews and linking this with meaningful outcomes (including biological endpoints).
- More integrated, cross sectoral approaches to research (including the arts and humanities) that continue to move beyond artificial barriers, siloed thinking, and territorialism—seeking to see connections between every issue.
- Address the commercial determinants of health and do more to recognize that the effects of marketing, which often escapes discourse, play a central role in manufacturing and maintaining the Anthropocene.
- Understand and promote the ways in which early life education can not only provide health assets, and character strengths for long-term health of individuals, but also promote emotional intelligence to create “planetary citizens” who will become wise ancestors.
- Continue expand the health paradigm beyond “disease” models toward greater aspirations of “sustainable flourishing” for all people and all places within planetary boundaries.

own health, their community, and the wider environment (Figure 4). There are now major international initiatives to promote nature-based solutions to bring more biodiversity and natural features and processes into urban landscapes. The European Commission recognizes that solutions “*inspired and supported by nature...are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience*”.⁹⁵ Even at the local scale, community efforts to “green” blighted urban lots show multiple benefits for physical and mental health, as well as improved community cohesion and less crime, violence, and fear.^{96,97} These practical strategies also build optimism, motivation, and engagement in efforts for sustainable change.⁹⁸

For individuals, regular contact with nature also improves health behaviors that can alter long-term health, including improved physical activity, eating behaviors, social behaviors, and lifelong nature connectedness.^{99–101} These multi-dimensional benefits of nature-based health interventions highlights the underutilized therapeutic and preventive potential of “green-prescriptions”—including green exercise, mindful nature-connection, wilderness art, therapeutic horticulture, biodiversity conservation, care farming, and nature play for children.¹⁰² In urban populations, higher nature-relatedness is linked to healthier dietary patterns.¹⁰¹ Even in preschool children, promoting nature relatedness in (with outdoor play and nature discovering) improves dietary habits, stress, activity, and attitudes to the environment, with measurable changes in the children’s gut microbiota.^{103,104}

Exposome science may offer a more sophisticated understanding of the relationship between green space, an individual’s personal interconnection within nature (nature relatedness), and health and wellbeing.^{105,106} At the same time, we can better understand how specific types of natural environments, especially human-designed green space within planned/restored residential communities, might promote the health of some, but contribute to the burden of allergic diseases in others.^{107,108} Moreover, with efforts underway to “re-wild” urban environments with vegetation and microbiome-inspired green infrastructure (MIGI)¹⁰⁹ to increase human contact with diverse microbiota (according to the microbiome rewilding theory¹¹⁰), evaluations using the exposome approach will be essential. In an encouraging example, a new study shows that indoor air-circulating “green walls” increased bacterial abundance and diversity on skin of office workers, and that this was associated with lower proinflammatory blood cytokine measurements (IL-17A).¹¹¹ In children, efforts to increase biodiversity in daycare yards (with sod from forest floors) increased both environmental and skin microbial diversity, which was, in turn, associated with increased regulatory cytokine levels and the proportion of regulatory T cells.¹¹²

A greater understanding of psychological relationships with nature, biodiversity, and potentially beneficial microbes, and how those attitudes and values intersect with biophysiological markers, will also be necessary. To this end, some have called for a deeper understanding of “microbial literacy” and how it might act as a pathway to more positive and constructive attitudes toward the microorganisms that underpin the ecosystems that sustain health along the personal, community, and planetary health continuum.¹¹³

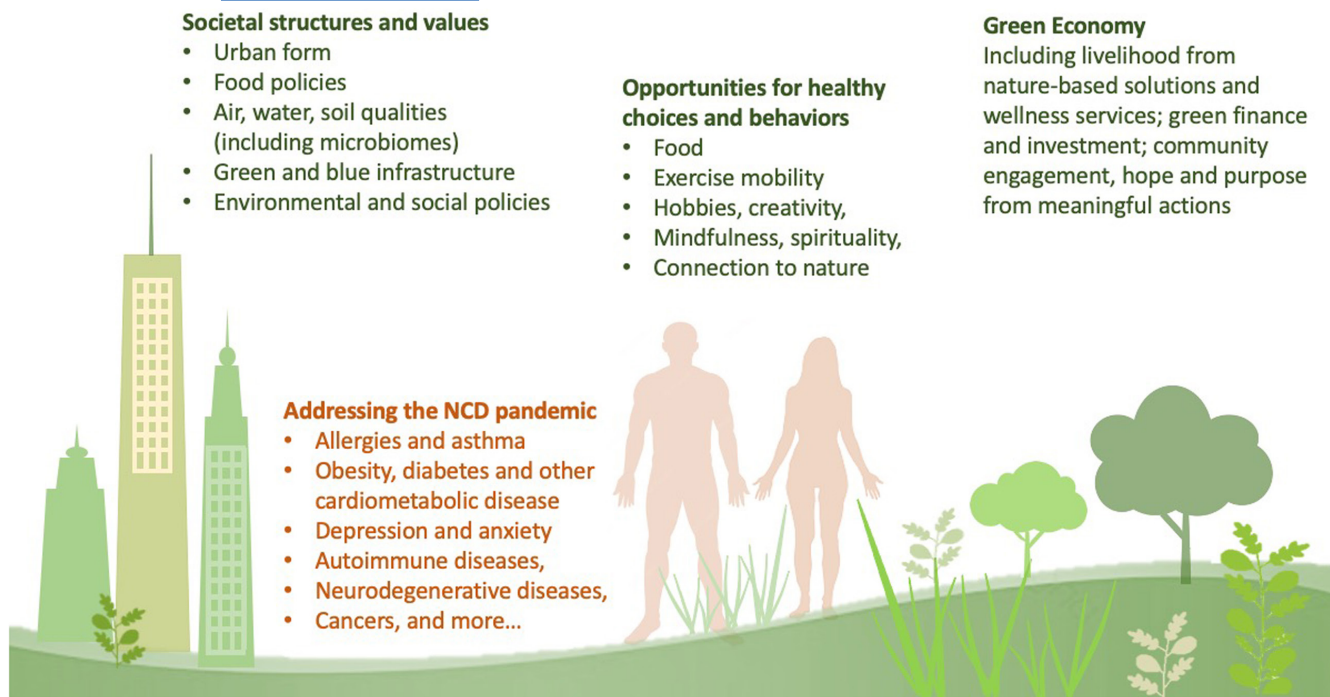


FIGURE 4 Co-benefits of nature-based solutions for the people, places and planet: Nature-based solution provide practical, tangible and co-beneficial ways to restore health of personal, societal, and planetary ecosystems. In the face growing environmental threats and human disease efforts toward ecological restoration are increasingly vital, including optimizing natural elements in everyday life. Personal efforts must be enabled by community efforts, which provide hope though meaningful opportunities for engagement in change. This depends on societal structures and green economies. (Adapted with permission from an original drawing by Eeva Furman and Tari Haahtela)

7 | PROMOTING A PLANETARY HEALTH MINDSET IS VITAL TO THE SOLUTIONS

Protecting human health and flourishing for all of life on Earth requires urgent, deep, structural changes in how we live.⁵⁸ However, this cannot be achieved without confronting the underlying value-systems and systems of exploitation and wealth concentration that created and continue to perpetuate our many global challenges of the Anthropocene in the first place, and strengthen efforts to heal territorial, adversarial, exploitative relationships with nature and each other.

Mutualistic attitudes depend on greater awareness and understanding of universal *“interconnectedness as a basic and fundamental reality...an awakened sense of interdependence between people and planet...that can stimulate psychological integration,”* personal well-being, *“and a sense of responsibility to the larger world”*.¹⁴ In essence, to promote the upstream determinants of health and flourishing we must equally consider our social and spiritual ecology as we do our natural ecology.

As cautioned by Richard Horton,³³ and from our own perspective, planetary health is not intended to be a re-tooled version of environmental health dominated by specific units of analysis, single indicators and/or jargon related to quantitative toxin-based environmental impact assessments. Indeed, the planetary health field has recently been criticized for focusing largely on technological and instrumental relationships between humans and biodiverse life on

Earth, while neglecting the commercial, economic, and political systems that underpin the grand challenges of the Anthropocene.¹¹⁴

Meaningful discussions of health at scale cannot exclude the commercial determinants of health, which may not operate in the interests of either human health or the environment,^{115,116} or actively cause great social damage and harm to health—as in the case of tobacco, alcohol, and ultraprocessed product corporations.¹¹⁷⁻¹¹⁹ Rather, planetary health requires challenging the powerful systems, many of them rooted in neoliberal ideology and the commercial distribution/marketing of unhealthy product, that underpin the presence of disease, and the absence of flourishing.¹²⁰ This includes addressing the power structures and propaganda employed to manipulate perceptions and maintain the status quo.³² These considerations must also include the unequal socio-eco-biological pressures, endured most by marginalized populations.¹²¹ We must seek to redefine “progress” and “growth” in more meaningful ways that place greater value on deeper wisdom and happiness, and quality over quantity. While technology will be a vital part of the solutions, it will be best applied with more mutualistic values, more investment in publicly beneficial infrastructure, and with more effort to predict potential adverse consequences. In his 1969 keynote, Dubos took a similar view: *“we must try to imagine the kind of surroundings and of life we want, lest we end up with a jumble of technologies and counter-technologies that will eventually smother body and soul”*.⁶

An appeal to values and wisdom may seem insufficient to the task of shifting mindsets responsible for the practices, policies, and

privileges that constitute what some have argued could more appropriately be called the “Capitalocene” than the Anthropocene.¹²² Nonetheless, the IPCC 2022 Mitigation of Climate Change report now identifies the need to consider “inner transition” and shifts in personal and collective mindsets in many aspects of sustainable transition strategies.¹⁹ Furthermore, the United Nations, along with many governmental and non-governmental organizations recognize that mindfulness can contribute to understanding and facilitating sustainability, not only at the individual level, but sustainability at all scales.^{123,124} As a result, mindfulness is emerging as a core concept in sustainability science, practice, and teaching, for further exploration of how awareness and “inner” transitions can contribute to shifts in mindsets for “outward” transformation.¹²⁵ Already, experts in allergy are aware of the emerging potential of mindfulness as a tool in managing clinical disease.^{126,127} From a planetary health perspective, we contend that mindfulness, or a planetary health mindset, has application beyond the individual.^{18,128} For example, mindfulness interventions at the policymaker level may help to improve perspective-taking, break “status quo” thinking and shift ways in which wellness is achieved at larger scales.^{129,130} Mindfulness has also been shown to help reduce polarization in the context of political issues,¹³¹ underscoring the value in promoting emotionally intelligent leadership.

Artists, poets, writers, and musicians also have a key role in creating new shared narratives to shift mindsets. They hold a mirror to society, provide hope, celebrate beauty, inspire action, and invite researchers to “ask the right questions”.²¹ In this, Indigenous traditional knowledges also add a much-needed vital dimension as one of several sources that “calls for an inclusion of wisdom that is not mere knowledge or information but is an insight that comes from the heart.”¹⁴

Thus, to fulfill its mission, planetary health must be inclusive of diverse perspectives on the determinants of sustainability, health, and the human connection to the Earth. Planetary health is inherently transdisciplinary and far broader than the biological and physical sciences. It includes the furthest branches of medicine, psychology, law, economics, the humanities, and political sciences. It requires listening to, integrating, and amplifying voices in every community—from Indigenous Peoples, faith traditions, creatives, entrepreneurs, to scientists, as “every person, in every place, from every calling, has a role to play in safeguarding the health of the planet and people for future generations”.⁵⁸

All these efforts must be underpinned by an intergenerational justice perspective that includes the interests and the voices of children and youth—recognizing that the health of tomorrow depends on the choices we make today.¹²¹ This encourages a long view, helps us see the determinants of health in novel ways,¹³² and invites greater consideration and responsibility to become “wiser ancestors”.¹⁸ Our call to action here, is to move the sustainability agenda from a technical challenge to a relational challenge, that requires restoration of reverence and sacred reciprocity with nature.^{133,134} This recognizes that relationships are not so amenable to “forcing” change rather, “they thrive on mutual respect, reciprocity, kindness, and yes that four-letter word... love”.¹³³

8 | CONCLUSION: THE FUTURE IN PERSPECTIVE

The field of allergy and immunology has been at the vanguard of what is now described as planetary health. The rapid global rise in allergic diseases in the 20th century provided international researchers with a virtually unlimited array of potential leads to follow. The environmental factors since uncovered by the profession—most notably, differing microbiota exposure, dietary changes, exposure to natural environments, and the lifestyles associated with urbanization and westernization—are applicable to NCDs in general, and are intricately interwoven with the grand challenges of our time. The multiple candidate contributors to allergic disease risk—urbanization, westernization, global spread of unhealthy products, diminished contact with biodiversity—are uncannily similar to the detrimental factors linked to disease and “dis-ease” at scales of persons, places, and the planet.⁹¹

The expanding concept of exposome science—the ability to examine total accumulated environmental exposures (both detrimental and beneficial) through large datasets—has the potential to predict the biological responses of the “total organism to the total environment.” Already, advances in microbiome science are indicating that external “ecosystems” (e.g., those that propagate unacceptable socioeconomic inequities, or those that control food policy, and the distribution/marketing of unhealthy products) can be manifest in the internal ecosystems of the human gastrointestinal tract.^{135–137} Thus, in addition to adding to exposome science, the microbiome and its associated dysbiosis is both an objective marker and metaphor for “life in distress” at community and even global scales.¹³⁸ If exposome science fulfils its promise, it will contribute to transforming how we measure and ultimately shape healthy, equitable, sustainable, and flourishing environments. As also noted by the 2022 IPCC report, “These shifts in values can occur when humans reconnect with nature, deepen their consciousness and take responsibility for protecting the planet and its climate”.¹⁹

To this end, by adopting a planetary health mindset,³ professionals in the field of allergy can continue to generate critical research, and clinicians can approach care with individual and community flourishing and the health of the planet in mind,¹³⁹ knowing that “our planet’s health and very existence depends on our remembering where we came from”.²⁹

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CONFLICT OF INTEREST

Dr. Haahtela reports personal fees from Orion Pharma, outside the submitted work. Other authors have no conflicts of interest to declare.

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