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SPECIAL SECTION ON PUBLIC HEALTH, CLIMATE CHANGE, AND ECOLOGICAL FUTURES: COMMENTARY

Intimate ecosystems: the microbiome and the ecological determinants of health

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Abstract
The ecological determinants of health make explicit the ways in which human health and well-being depend on the biosphere and its systems. Water, oxygen, and food are listed along with soil systems, water systems, material for shelter, energy, the ozone layer and a stable climate. Research in the sciences is uncovering the critical role that the earth microbiome, including the human microbiome, plays in human health. The relationship between commensal microbiota and the systems of the human body, as well as the ways in which these systems are interdependent with other ecosystems such as food systems, invites revisiting the ecological determinants of health. In this commentary, I argue that microbiota, including the human microbiome, should be considered ecological determinants of health. Such a characterization would recognize the importance of the microbiome to human health. It would also frame this as a public health issue and raise questions about health equity, including who benefits from the knowledge produced through biomedical research.

Résumé
Les déterminants écologiques de la santé rendent explicites comment la santé et le bien-être humains dépendent de la biosphère et de ses systèmes. L'eau, l'oxygène et la nourriture figurent parmi ces déterminants comme également l'écologie du sol, le réseau hydrographique, les matériaux d'hébergement, l'énergie, la couche d'ozone, et un climat stable. La recherche dans le domaine des sciences révèle le rôle critique que joue le microbiote humain dans la santé humaine. Les rapports entre les microbiotes commensales et les systèmes du corps humain, y compris les interdépendances entre d'autres écosystèmes tels les systèmes alimentaires, invitent une réexamination des déterminants écologiques de la santé. Je soutiens, dans ce commentaire, qu'on devrait considérer les microbiotes, y compris le microbiote humain, des déterminants écologiques de la santé. Un tel caractérisation reconnaîtrait l'importance du microbiote vis-à-vis la santé humaine et le situerait dans le cadre d'un problème de santé publique. En plus, il soulèverait des questions sur l'équité en santé y compris la question de qui va bénéficier du savoir qui découlerait de la recherche biomédicale.

Keywords Microbiota · Public health · Ecosystem · Human body

Mots-clés Microbiote · santé publique · écosystème · corps humain

The ecological determinants of health (Canadian Public Health Association (CPHA), 2015) articulate the dependence of humans on the biosphere. Oxygen, water, and food are determinants of health; so too are soil systems, water systems, materials for shelter, energy, as well as a stable climate and ozone layer. The concept was articulated by a Canadian Public Health Association (CPHA) working group and foregrounds the often-neglected fact that "human survival fundamentally depends on a diversity of other life forms, which in turn are interdependent themselves" (CPHA, 2015, p. 2). Building on scholarship in subfields such as One Health and ecohealth, the concept makes a significant contribution to the discourse. Not only does it

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offer scholarly theorization of the human relationship with nonhuman nature, but it also provides a conceptual tool that can be applied in public health practice and policy. Importantly, it is pertinent to the Anthropocene epoch when climate change and environmental degradation threaten the functioning of these very systems that human health depends upon.

Recent research into the earth microbiome (Thompson et al., 2017), including the human microbiome, invites revisiting the ecological determinants of health. There is a growing understanding of the profound interdependencies between human health and microbiota. Technological advances have enabled researchers to identify new microorganisms, isolate their DNA to sequence, and learn about metabolites and proteins produced by microbiota (Manasson et al., 2020). This work has revealed an interdependency so profound between humans and microscopic lifeforms that inhabit our bodies and our environments that it has been suggested that animals and plants, as described in a *PLOS Biology* publication, should not be seen as "autonomous entities but rather as biomolecular networks" (Bordenstein & Theis, 2015). While some microorganisms are of course pathogenic, it is now understood that common perceptions of bacteria, viruses, and other microorganisms as mostly dangerous to human health are false. Rather, these microorganisms are fundamentally health-determining.

In the same way that water, food, and oxygen determine human health, microorganisms do too. For example, the microbiome of the built environment has an impact on human health (National Academies of Sciences et al., 2017). Microbes are critically relevant to water systems as well as food systems. Microorganisms are central to soil systems and support the fertility that allows plants to produce food. But the most intimate example of how microorganisms determine human health is found in the human microbiome, defined as microbial communities that reside in and on the human body including on our skin and in our guts (O'Doherty et al., 2016). Discoveries in the biomedical sciences reveal that microbes play an important role in the immune system (Hooper et al., 2012), they facilitate digestion and gastrointestinal well-being (Valdes et al., 2018), and even have a part in mental health (Peirce & Alviña, 2019), among other conditions. Thus, the earth microbiota, including the human microbiome, should be considered one of the ecological determinants of health. Recognizing such health-supporting interdependencies between microbes and ecosystems, including the human body, as ecological determinants of health frames this as a public health issue. It also raises questions about equity, the common good, and who benefits from these emerging health insights.

The human microbiome and public health

While many aspects of the earth microbiome can be said to be human health-supporting and sustaining, in this article I focus on the human microbiome, our resident communities of microorganisms. The U.S. National Institute of Health, Human Microbiome Project, has characterized communities of urogenital, gastrointestinal, skin, oral and nasal microbiota (https://hmpdacc.org/hmp/). Here, I focus on gut flora as they are pertinent to public health through their role in nutrition and their connection to food systems, as well as their important role in the immune system and chronic diseases, such as inflammatory arthritis (Brandl et al., 2021).[1] The human colon is the habitat for various genera of bacteria and other microorganisms. Some of these microorganisms are commensals, belonging to bacteria species such as Bifidobacterium and Lactobacillus, that have co-evolved with the human intestinal tract over millenia. Others can be pathogenic, such as *E. coli* and Shigella that cause dysbiosis, which is disturbed gut microbiota (Lloyd-Price et al., 2016). Medical research is uncovering the diverse roles that commensal bacteria play in the functioning of the human body. For example, colonic bacteria digest dietary compounds in plant-based foods and allow the body to absorb short-chain fatty acids that otherwise are not available to humans. Short-chain fatty acids are important to immune system regulation and are anti-inflammatory—they help to reduce the risk of cardiovascular disease, for example (Chambers et al., 2018). Gut flora make these compounds available to the body by fermenting plant fibres that we eat. Testimony to the long-standing relationship that has evolved between humans and gut bacteria is the fact that breast milk contains hundreds of oligosaccharides that are indigestible by the baby but are produced by the mother to feed the bacteria in an infant's gut (Yong, 2016). Since commensals are dependent on particular foods to thrive, what one eats is even more determinative of health than previously thought. A healthy gut biome is one in which a diversity of these beneficial microbes thrive.

But in the same way that ecological biodiversity has been dramatically damaged by industrialization, so too has the human microbiome. The diversity of gut flora has diminished substantially in industrialized societies due to a mix of factors including the overuse of antibiotics and the nutrition transition to industrial diets (O'Doherty et al., 2016; Sonnenburg et al., 2016). Not only do antibiotics kill pathogenic bacteria, they also kill beneficial ones which is why their overuse is blamed for a reduction in gut flora. Diet shapes the microbiome in that commensal gut bacteria thrive on

[1] Researchers are uncovering the importance of microbiome to many of the body's systems and the role that microorganisms play at every stage of life from birth to old age.

foods high in compounds that are often referred to as dietary fibre. These insoluble fibres, also known as microbiota-accessible carbohydrates, pass through the human stomach to feed the microbes in the intestines. But the food served up by the industrial food system, that is high in sugar, animal fats and refined grains that have been stripped of their bran, germ, and endosperm to render them suitable to the logics of industrial production, does not have the same effect. The diminishment of biodiversity of the human microbiome has inspired the non-profit Microbiome Conservancy to collect microflora from so-called traditional communities in Thailand, Malaysia and Senegal (for a critique of the colonial practice of extracting gut flora from Indigenous communities for development of therapeutics, see Hobart & Maroney, 2019). As such, there are calls for stewarding of the microbiome (O'Doherty et al., 2016).

The earth microbiome and the ecological determinants of health

Recognizing the earth microbiome as an ecological determinant of health deepens an understanding of the interdependence between human health and well-being and nonhuman lifeforms and systems. It makes clearly visible the fact that a human being is not an independent, self-sustaining individual but rather survives and thrives as the result of ecosystems and a diversity of life forms. Other public health frameworks for thinking about microbiome research have flagged issues such as considering the long-term consequences of therapeutic interventions and their ramifications for communities, microbial stewardship (O'Doherty et al., 2016), and the importance of microbial science training in public health (Wilkinson et al., 2021). But labelling these microflora as ecological determinants of health shifts discussion to focus on the collective in a public health context and raises questions related to equity. The World Health Organization (N.D.) defines health equity as "the absence of unfair and avoidable or remediable differences among population groups". When applied to the microbiome, health equity would mean that there should be no differences among groups in exposures to microbiota, relationships with commensal and mutualist microbiota, and attendant health outcomes as determined by earth microbiota, including the human microbiome. An equitable approach to the human microbiome would include ensuring that groups have equitable access to the conditions that support a healthy resident gut community.

The human microbiome is not static and changes depending on how we interact with the world, including through our diet and our physical intimacies (Kort et al., 2014). An individual's microbiome exists in relation to what O'Doherty et al. (2016) call a "collective microbiome" that includes not only the microbes of the people we live with but also the microbes in the environment that can be affected by activities such as livestock agriculture and our buildings (Wilkinson et al., 2021). If a person's microbiome is determined by interactions with the world around them, including the collective microbiome, then responsibility for stewarding and caring for this ecological determinant of health becomes a social issue too. The collective microbiome is a non-excludable common good, just like clean water and breathable air. Who benefits from a healthy microbiome and who does not is thus a health equity issue.

Further, calling the earth microbiome an ecological determinant of health raises questions about the ways that scientific discovery in this field is commercialized versus serving the common good. Currently, microbiome research is being monetized as microbes are commodified into therapeutics and other products (Greenhough et al., 2020). MIT's microbiome "library" sells researchers products including the "Diversity Box," a collection of 106 microbial species for $5000 USD (The Broad Institute, 2019). The refrigerated sections of natural food stores are filled with costly probiotic products and a search for "probiotic" in the Canadian Intellectual Property Office database yields more than 2 million documents. In the medical literature, it is suggested that "personalized nutrition recommendations" could tailor microbial-based treatments for individuals with conditions such as migraine (Slavin et al., 2019, p. 1574). The commercialization of the research renders the microbiome an issue of individual health. However, as becomes evident when the earth microbiome is characterized as an ecological determinant of health, it is in fact a *public* health issue. To think of these lifeforms this way begins to undo the privatization of the benefits of research.

In the rush to learn more about the microbiome, it is important to remember that microbes are not all good—we cannot forget the Pasteurian successes of better controlling pathogenic bacteria in the food supply and the body. In designating the microbiome an ecological determinant of health it is also important not to lionize microbiota as what Paxson and Helmreich (2014, p. 171) call a "model ecosystem" that are held up as "moral exemplars" and that risk being "prescriptive" in "human cultural products." While keeping these risks in mind, it nevertheless would be a beneficial addition to public health discourse to reconsider the ecological determinants of health to include the earth microbiome.

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Declarations

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