Shit, in Silico
On the Postcolonial Materiality of Bioinformation

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"Biology" does not speak for itself, either about humans or nonhumans. Biological material is not a substance to be read in a simply literal mode. It cannot be. Rather, biology is a historically crafted discipline, and its materials come thickly figured and configured by the histories and cultures through which they are imagined and inhabited. The biological is more than biological.
—**Stefan Helmreich, *Sounding the Limits of Life***

In March 2022, high-level negotiations took place at the United Nations Convention on Biological Diversity (hereafter Biodiversity Convention) to ascertain the status of *digital sequence information*, the policy term used for information derived from biological resources and genetic material.[1] Core to the negotiations was the issue of benefit sharing, a central mechanism of the Biodiversity Convention to ensure that countries that provide biological material (usually biodiverse countries in the South) to scientists and pharmaceutical companies (usually those in the North) receive recompense for their contribution to scientific development and commercial applications.[2] While the convention has long secured benefit sharing

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1. For instance, from organisms, plants, microbes, viruses, or human biological material. In other circles the term *genetic sequence data* is used instead.

2. Besides the Biodiversity Convention and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from Their Utilization (hereafter Nagoya Protocol), access and benefit-sharing rules for biological materials have also been defined in the Food and Agriculture Organization of the United Nations' International Treaty for Plant Genetic Resources for Food and Agriculture, and the World Health Organization of the United Nations' Pandemic Influenza Preparedness Framework.

for biological *materials*, the status of biological *information* is contentious. To include bioinformation, developing countries seek to tether data to the nation-state. Critics—often represented by developed countries—say instead that data must flow; they see benefit sharing as a legal hurdle that will hamper scientific progress.

The debate on bioinformation and benefit sharing comes at an unprecedented time. The COVID-19 pandemic showed once again how arrangements around global science and global health widen the inequality between the Global North and the Global South. Despite the promise of supranational regulation and the collective global effort that went into the production of key COVID-19 vaccines (including clinical trailing in the South), vaccine nationalism and intellectual property (IP) claims continue to militate against the equal distribution of lifesaving vaccines. These conditions inhibit Southern nation-states' ability to create robust scientific institutions. At the same time, the largest crisis of all crises is looming in the background. The climate crisis functions as a constant reminder that the future of the planet depends on science and technology—on experts, data, and the political will of states and communities—to inform our course of action.

This essay interrogates the problem of materiality in assessing bioinformation for benefit-sharing purposes.[3] Its aim is not to contemplate how best to govern digital sequence data, or to advocate for either data sovereignty or open access. I hope, instead, to clarify the different scales at work in thinking about the materiality of bioinformation, and to identify ways in which the "more than biological"—as Helmreich (2016: 72) so eloquently describes it—is folded into the biological, including, I argue, digital biology. Rather than focus on the conventional ethico-legal paradigms of privacy rights on the one hand and the public commons on the other, the essay asks how bioinformation, or the datafication of biological resources, is tethered to history, environment, society, and culture. How do formations of biodata in contemporary scientific practices—translational, economic, legal, social, political—inform new relations of knowledge and value? And what are the implications of these (re)configurations for (global) governance?

I do this by focusing on data extracted from human stool for research on the human gut microbiome—a pioneering bioscientific field with great promise for tackling various diseases. I examine how stool transitions from in vitro to in silico analysis; how fecal materials are turned into metagenomic sequence data. Drawing

3. Under the Biodiversity Convention and the Nagoya Protocol, *genetic resources* are understood as "genetic material of actual or potential value," and *genetic material* is defined as "any material of plant, animal, microbial or other origin containing functional units of heredity" (Bagley 2020: 28). The tangibility of materials is understood as dividing biological resources from the information flowing from them and therefore prevents the inclusion of DSI in the definition of *genetic resources* (see Bagley 2022).

from the social study of postgenomic biosciences (Helmreich 2015; Mansfield and Guthman 2015; Meloni 2018; Reardon 2017; Rajan and Leonelli 2013; Richardson and Stevens 2015; Stallins et al. 2018; Van Wichelen and Keaney 2022) and the anthropology of bioscience governance (Hayden 2003; Parry 2004; Pottage 2006), I argue that the dematerialization of stool is simultaneously accompanied by processes of *re*-materialization that "thicken" metagenomic data. In the same way that Clifford Geertz (1973) used "thick descriptions" to interpret cultural "information," the "thickening" of data in microbiome research occurs through a postgenomic context informed by the following conditions: (1) the epistemic infrastructure through which scientists interpret microbiomic data; (2) the challenges microbiomics bring to regulatory capitalism; and (3) the postcolonial materiality of microbiomic knowledge. These conditions demand critical reflections on the governance of scientific exchange in the era of digital biology, beyond the polarized present that posits data sovereignty on one side and a Mertonian scientific commons on the other.

Analyzing Microbiomic Data

Recent research into the human microbiome anticipates that biological processes occurring in the body cannot be disentangled from the microorganisms that inhabit it. Various microbes—bacteria, fungi, archaea, and viruses—populate the body—particularly the gut, skin, mouth, and vagina—in such magnitudes and varieties that some biologists have proposed we think of the body as being part of a distinct form of microbial ecosystem. They call this the *human microbiome*. Scientists argue that microbes are not only along for the ride; they do not merely live in and on our bodies for their own survival. Rather, gut microbes extract energy from food, modulate the immune system, and keep pathogens from multiplying.

In the past two decades, the number of publications that concern the human microbiome has exploded.[4] Scientists and popularizers hail human (and nonhuman) microbiome research as the bioscientific revolution of the twenty-first century.[5] Within a relatively short time span, researchers have linked diseases—ranging from obesity, diabetes, asthma, and autism, to cancer and even neurodegeneration—to certain conditions of the human microbiome. Scientists also generate claims about

4. A simple search of the term *human microbiome* in PubMed generates a dramatic increase in publications over the past two decades. Before 2001 there were fewer than 100 publications per year. From 74 publications in 2001, the number grew exponentially to 21,648 publications in 2021.

5. Microbiome research extends far beyond the focus on humans. The first life forms on earth were bacteria, and we can find bacteria everywhere, from our garden soil to glaciers and hot springs. Research on human microbiomics receives the bulk of the funding, however, prioritizing the translational work from science to medicine.

the gut-brain axis, suggesting a link between poor gut health and mental health issues, such as anxiety and depression. It is vital to note that although the science is promising, most of the studies conducted concern associations and do not give solid evidence of causality (O'Malley and Skillings 2018; Parke, Calcott, and O'Malley 2018; Bik 2016). What we can safely say is that gut microbiomes differ from person to person; that often, diseased bodies have a less diverse community of microbiota (also called dysbiosis); that the microbiome fulfills an important function in the absorption of drugs; and that transplanting a diverse microbiome into a human body suffering from certain colon-related diseases can either cure them or alleviate them of many symptoms. Current medical treatments include fecal microbiota transplantation and helminthic therapies, while public health initiatives have focused on nutritional interventions (including the use of probiotics and prebiotics).

Scholars from the social sciences and humanities have characterized microbiome research as a postgenomic science. This classification reflects the changing conditions of knowledge production following the human genome project, where the life sciences have entered a new phase in "research methodology, funding, scientific labor, and disciplinary structures" (Richardson and Stevens 2015). The massive expansion and intensification of sequencing technologies and capacities in bioscientific research are main drivers of the postgenomic condition and bring multiple forms of uncertainty to the status of biomaterials and bioinformation. They lead to new challenges in the valuation, classification, and provenance of data and of their providers, annotators, and curators (Ankeny and Leonelli 2015). While sequencing technologies allow materials to become data, their analyses become part of an aggregate shared across (private and public) practitioners and are increasingly undistinguishable in terms of locating their origins or trajectories. At the same time, the computing power of metagenomic data systems allows the disclosure of unique information about individuals, raising privacy concerns similar to those within human genetics when information was collected from blood and swabs.

Within microbiome studies, human stool samples are sequenced for large-scale computational research on the human microbiome. These technologies—associated with shotgun sequencing and the development of metagenomics[6]—have radically changed the science, transforming what kind of knowledge is legible, valued, and calculable (Leonelli 2015; O'Malley and Skillings 2018). As bioinformatics becomes the primary activity (over collecting and culturing), ethico-legal challenges of scientific exchange move from materials to information. The Biodiversity Convention has yet to govern bio*information.* The existing requirements

6. Technologies that speed up the analysis and identification of organisms' genomes.

around material transfer agreements (MTAs) apply only to *materials*. Consequently, on-the-spot sequencing—the quick translation of stool to data (for instance on a phone)—releases scientists, universities, or companies from having to meet legal requirements of material transfer.

In her ethnographic study of microbiome research on infant malnutrition in Dhaka, the anthropologist Amber Benezra (2016) describes the datafication of microbes and points to how big data-producing technologies, machine learning, and metagenomics turn Bangladeshi children's bodies into the data for transnational and translational research in the hopes of finding a technological fix for malnutrition. The bacterial taxonomic biomarkers indicate conditions of malnourishment, which allows local data to inform standardized health interventions (346). Here, social behavior and circumstances concerning infant malnutrition in Dhaka were morphed into computed data and made available for mining, analysis, and prediction.

As postgenomic methods increasingly datafy biological material, much of the information extracted (in our case from stool) becomes decoupled from its origins. But contrary to the assumption that data are freestanding, neutral, and factual, the microbiomic data described in Benezra's study are valuable only in connection to information about the diets, health, and local lives of the subjects in Bangladesh. The connection between data and place, and between data and scale, is vital in terms of scientific value; while the data "travel" to databases and become untethered from their local origins, scientists accessing the data tether them back to certain localities depending on the research questions and the new context they put the data in (see also Leonelli 2010: 150). The origins of data become relevant when scientists seek to validate the quality of their claims.

What happens here is that information attached to these localities becomes aggregated with the microbiomic information, thereby "molecularizing" environments, biographies, and milieus (see also Landecker 2011; Niewöhner 2011). Once "context" becomes integral to the microbiomic data collected, the "social" becomes part of the biological. Geographers (Davies 2013; Stallins et al. 2018) speak of the mapping work that is inherent to postgenomic sciences, where biodata—regardless of their "bigness"—require local and contextual information to make them legible for scientific practice. A closer look at the process of "re-localization," however, reveals that the enterprise of postgenomics is antithetical to, rather than contingent on, a "thick" form of context. In the next two sections, I describe how mapping of the human microbiome makes bioinformation valuable for commercial purposes while creating "geographies of difference" (Stallins et al. 2018: 160) that tether bodies to places without due care for historical or ethnographic context.

Microbiomic Value and Regulatory Capitalism

According to the philosopher of science Sabina Leonelli (2010: 133), translational research is characterized by the commodification of biology and both public and private sectors are invested in the right sort of governance so that the translational work can be developed. Broadly speaking we can divide global bioscience governance into two groups. On the one hand we have private regulatory frameworks (intellectual property rights, private international law) that make biomaterials and bioinformation monetizable, fungible, and tradable. Here patent and contract law have been instrumental in guiding the circulation of biotech materials and research tools. On the other hand, public regulatory frameworks aim to protect society from the vagaries of the bioeconomy. Here, biodiversity and health laws either put limits on markets or regulate them for the common good. The latter can be observed in ethico-legal techniques (informed consent, material transfer agreements), bureaucratic practices (audit cultures, best practices), and discourses (scientific or medical progress toward human advancement). Postgenomic data challenge foundational principles across private and public bioscience governance frameworks (see also Van Wichelen and De Leeuw 2022). Microbiomics offers a good example, which I will illustrate here through the ethics of microbiomic data collection (public) and the patentability of precision microbiomics (private).

In contrast to genetic researchers, who must undergo many ethico-legal hurdles to collect DNA samples, particularly from Indigenous communities (Kowal 2013; Radin 2013), it is still relatively easy for human microbiome researchers to collect stool samples and to bypass transfer agreements common to human genetic material. Shit is ubiquitous and free. It is not extracted from the body like a kidney for transplants, or a swab for DNA cells, nor does it have the cultural appreciation that is attached to human blood, placenta, or breast milk. While in many jurisdictions feces is considered (bio)waste, legal scholars advocate changing the legal definition of stool to be included as human tissue, arguing that stool may hold value similar to placenta and human breast milk (Cohen 2021). The (legal) recognition of stool as biologically one's own would ignite the same kind of ethical debates presented by human tissue (Waldby and Mitchell 2006), where the question of whether one owns one's tissues is inextricably informed by a (legal) philosophical attachment to human individuality.

Yet, the very idea of human individuality is changing among the postgenomic biosciences, which leaves uncertain the legal status of human stool, human microbiota, and human microbiomic data. Scholars in the social study of science have shown how microbiomics disturbs traditional notions of humanness and biological personhood. The human microbiome is a more-than-human or multispecies affair, involving the life and labor of tiny organisms—trillions of microbes—inside the human body, and their dynamics vis-à-vis environmental conditions outside of the body (Helmreich 2015; Lorimer 2016; Greenhough et al. 2020; Paxson 2008). What is reidentified is not so much the subject herself as the more-than-human assemblage constituting the microbiome, which can include the natural and built environment (dirt, chemicals, pollution), diet (food and nutrition), medicine (antimicrobials), and organisms both inside (microbiota or hookworms) and outside bodies (pets and wildlife). The challenge for public regulation, then, is how to govern microbiomic data as a *spatiotemporal assemblage*, rather than as information attached to an individual. In true Latourian manner, microbiomic data—like ferment in the pasteurization of France (Latour 1993)—become a substance that specifies the stability of an assemblage; rather than hiding (true) information about the self, microbiomic data develop into an "institution" (111) held together by technoscientific and local practices.

The other side of the governance spectrum encompasses intellectual property rights with the aim of assisting invention and commercialization. Commentators have observed the rise of probiotic markets in many parts of the world (including Asia and the Middle East), where "good bacteria" are capitalized to promise health and well-being (Lorimer 2019; Greenhough et al. 2020). But often microbiomic research is not funded with earmarked capital for a well-defined market. It relies instead on what the sociologist Charis Thompson (2005) has called "promissory capital," where microbiomic data are valuated for their potential uses, promises of returns are speculative, and the value of microbiomic data "unfolds over time" (258). The framing of microbiomics as the next pillar in precision medicine is a fitting example of promissory science. So-called precision microbiome testing through sample screenings or the use of "smart toilets" offers personalized analysis to detect disease. Interestingly, the bioinformation brought back to the patient-consumer via precision medicine brings novel problems to patent law and intellectual property rights.

The legal historian Mario Biagioli and the anthropologist of science Alain Pottage describe for instance how the turn to bioinformation is impacting the core principles of patent law. Analyzing the history of patentability via the context of plant breeding, biotechnology, and now "diagnostic medicine" (central to precision medicine), the status of bioinformation disturbs the notion of invention that is core to patent law. As they argue,

> Bioinformation abstracted from the body is returned to the body as a prompt for the body's own information-processing circuitry. It is this shift from an

industrial or manufacturing paradigm to a bioinformational paradigm that informs the new sense of invention. (Biagioli and Pottage 2021: 233)

Patent law—troubled by developments that stress biological processes in silico rather than in vitro—upsets the figure of nature (discovery) central to law's demarcation from culture (invention). Translated to microbiomic data, we can distill from this argument that the diagnostic testing involved in precision microbiomics is based on the discovery of information about the diversity of certain microbiomes; rather than the creation of curative microbiomics, the discovery of a particular formation of microbiota *is* the invention. Or, to put it differently, whereas the "old" genetics depended on an industrial logic "that construes 'nature' . . . as an input for the production of pharmaceutical products," postgenomic precision medicine depends on a cybernetic logic that understands nature as "diagnostic information that is used to fine-tune therapeutic procedures" (Biagioli and Pottage 2021: 233).

If regulatory frameworks are to move "invention" *toward* rather than away from nature, they can expand the commodification of nature to include even the law of biology itself. Moreover, referring to the work of the historian of science Hannah Landecker, Biagioli and Pottage show how the promissory capital generated for translational research operates by "deliberately fus[ing] ends to means, making the end goal of the research directly and explicitly shape its character from the get-go" (Landecker 2013: 498). This means that in microbiomics, for instance, the goal of precision medicine directly frames scientific inquiry, which, as we have observed, is focused on the spatial mappings of distinctive microbiomes. The point is that commodification doubles down on the spatial aspects of research. My final reflection on bioinformation's materiality concerns the postcolonial politics of such spatial mappings: How are translational properties of microbiomics entangled to conditions of neoliberal capitalism and global imperialism? Those entanglements, I propose, should give us pause when deliberating the ethical transfer of bioinformation.

Postcolonial Materiality of Microbiomic Knowledge

One of the central premises underlying much of the recent human microbiome research is that geography, culture, and diet hugely influence the diversity of our microbiomes (Stallins et al. 2018: 161; Bik 2016: 364). These studies indicate that Westerners—more precisely, human bodies who are living urban and industrialized lives—have a less diverse gut microbiome compared to people living in subsistence economies or people living in hunter-gatherer communities. There are strong indications that less diverse microbiomes are linked to metabolic disorders that are prevalent in Western populations but not as widespread in subsistence economies and are even absent in hunter-gatherer communities. Over time, the gut microbiomes of people in (over)developed countries have progressively endured the digestion of sugars, fats, and proteins. Industrialized Westerners live in sanitized environments, their livelihoods lack frequent contact with their immediate natural environments, and their overuse of antibiotics significantly reduces the diversity of the gut microbiome. Preindustrialized microbiota are key to curing these industrialized bodies, leading to what has been called the bioprospecting of Indigenous guts (Benezra 2020: 883). In contrast to earlier bioprospecting (for instance, of plants or humans, which relied on the relative stability of DNA sequences), the "spatiotemporal character" (Stallins et al. 2018: 157) of postgenomics (including microbiomics) makes bioinformation erratic and variable. It is also this very same spatiotemporal character that makes microbiomic information valuable for capitalization.

Popular accounts of human microbiome research include promissory narratives where fecal transplantation, helminthic therapies, certain diets, or probiotics can cure all kinds of ailments of the modern Western world and its devastating effects on the human body: the obese body, the polluted body, the diabetic body, the antibiotic-resistant body, and so on. Accounts like those that urge us to "rewild" our gut (Lorimer 2019) place the bodies of those who live preindustrial lives (such as hunter-gatherers, Indigenous communities, or agrarian cultures) in a new idiom of "bioavailability" (Cooper and Waldby 2014) where the potential for "extraction" and commercialization is vast. Capital accumulation in microbiomics relies therefore on the knowledge of "embedded bodies," those that metabolize through interactions with their inner and outer environment (Niewöhner 2011: 290; see also Keller 2010; Lock and Palsson 2016). Today's division of the human microbiome into those from urban, industrialized, and (over)developed places against those from undeveloped, preindustrialized, and subsistence economies make certain bodies more treasured for extraction. Not just any shit is valuable, only from those bodies embedded in subsistence economies.[7]

In his work on American public health and the poetics of pollution in the colonial Philippines, the historian of medicine Warwick Anderson (1995, 2010) vividly describes the medical production of colonial bodies. The tropical environment, he argues, "called for massive, ceaseless disinfection; the Filipino bodies that polluted it required control and medical formation; and the vulnerable, formalized bodies of the American colonialists demanded a sanitary quarantine" (Anderson 1995: 641).

7. See also Gil-Riaño and Tracy 2016 for a longer discussion of white Euro-American discourses on the somatic effects of modernization and colonial discourses of fiber.

Anderson describes how the new tropical medicine which emerged at that time "informed an expanded apparatus of surveillance and regulation in the archipelago [and] worked to reproduce in parallel the formalized body and the abstract space of colonial modernity" (Anderson 1995: 667). The idea of bodily control extended the powers of colonial modernity, and excremental politics were at the heart of distinguishing the modernized American from the abject Filipino. Nevertheless, even as they saw feces as dangerous, American scientists were obsessed with collecting specimens of Filipino stool. This was only possible—Anderson argues—because of the "ritual frame" of the laboratory, which "permitted accredited scientists to smear the pulverized, reduced material on their microscope slides and agar plates with abandon. . . . The decent, delibidimised, closed space of the modern laboratory had conferred on shit the "epistemological clarity" of just one more specimen among many" (Anderson 1995: 669). Returning to the present, the desire by (entrepreneurial) scientists to map the human microbiome demonstrates a new obsession with excremental matter. But rather than reproducing the developmentalist imaginary that portrays transitions from subsistence economies to industrial economies as inevitable progress and enlightenment, we witness a reverse of this colonial pathos in the domain of microbiome research.[8] As opposed to banking on the colonial trope that renders white souls "pure" and sanitary, modernized subjects are seen as deficient instead.[9] Yet, while reversed, the racialized dimension remains intact in the postcolonial rendering of microbial difference. As the transition from a subsistence economy to an industrial economy robs industrialized bodies of their capacities to metabolize efficiently, the microbial knowledge of "other" bodies is put to work to remedy these pathogenic instances.

Bringing these matters back to the question of governance, the bioprospecting of "other" bodies through the datafication of their microbiomes creates a paradoxical situation: while global health imperatives continue their modern pursuits of hygiene, sanitation, antibiotic treatments, and deworming in the South, scientists and pharmaceutical companies use microbiomic data from these very same localities to carve out new markets for probiotics, prebiotics, and helminthic therapies (Lorimer 2016: 59; Benezra 2016: 347).[10] One can detect in this case the construction

8. And in that of nutrition science, which is becoming more and more important and powerful today.

9. This reversion of the colonial pathos—and the upending of shit's value—is not new and can be witnessed in the history of the dietary fiber paradigm described by Gil-Riaño and Tracy 2016. This paradigm de-pathologized the premodern defecating body, and instead "pathologized the retentive body of the modern citizen, holding fast to the white loaves of progress" (199).

10. Interestingly, the research practices geared at the global microbiome therapeutics markets differ from research on the "super donors" for fecal microbiota transplantation, who are all Caucasian male.

of a “postcolonial materiality” (see also Warin et al. 2022) where microbiomic data are not only tethered to spatiotemporal contexts (those that affect metabolism), but also folded into scientific, biomedical, and global health practices that continue to operate on a colonial logic. Microbiomic data, then, toggle between competing narratives, of humanitarianism and economy, scientific progress and global inequality, bioprospecting and biopiracy, and data sovereignty and “open science.”

Working at the interstices of precision medicine and (global) public health, the critical analysis of microbiomic data offers complex insights into the simultaneous durability and mutability of materiality. Resembling other trends in epigenetics and immunology, the postgenomic condition of microbiome research challenges foundational dichotomies between nature and culture, and between bodies and the environment. Its biological materials are not individual or compartmentalized wholes, but biosocial formations and molecularized environments. New understandings of bioinformation bring to governance new challenges, both for intellectual property rights and for benefit-sharing arrangements. Here, microbiomic data—and bioinformation in general—should not be regarded as “raw,” “untethered,” or “neutral,” but instead as in need of careful attention and analyses to see how information relates to complex histories, cultural contexts, and biosocial environments. The next step would be to see how we can enlist and implement materiality into new forms of legal instruments, designed, not from a desire to access or control, but from a desire to relate and cohabitate a more just world and sustainable planet.

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