Gut Buddies

Multispecies Studies and the Microbiome

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Abstract Recent work in the life sciences presents the human as a superorganism, composed of and kept alive by diverse microbial kin. We learn that this life is changing fast as a result of modern lifestyles and that missing microbes are causing epidemics of absence. There is a growing interest in restoring components of the microbiome. This article explores some of the implications of these developments for multispecies studies through a focus on helminth therapy—the selective reintroduction of parasitic worms as "gut buddies" to tackle autoimmune disease. It first traces the visceral vectors, cycles, and assemblages through which people are differentially entangled, disentangled, and reentangled with helminths. It then analyses these entanglements with reference to literature on the science and politics of (auto)immunity. The article places helminth therapy in the vanguard of new ways of enacting immunity. Scientists writing about helminths are reworking binary, martial models of immunity as the defense of the self to consider immunity as the tolerance, recruitment, and creative experimentation with microbial symbionts. Here immunity is enacted in contrasting multispecies assemblages that illustrate the communal and the immunitarian characteristics of contemporary biomedicine. In conclusion the article reflects on how the probiotic relations of helminth therapy suggest new ways of thinking of companionship and hospitality as more-than-human, but not posthuman, achievements.

Keywords microbiome, helminths, immunity, helminthic therapy, multispecies studies, post-Pasteurian

Life in Us

Recent findings from the Human Microbiome Project suggest that a great deal of "us" is not us.[1] In oft-cited figures, we are diminished to only 10 percent or 1 percent human, depending on whether our essential identity is pinned to human cells or genes,

1. The Human Microbiome Project was a US National Institutes of Health initiative that ran from 2008 to 2013. It aimed to identify and characterize all the microorganisms found in association with both healthy and diseased humans. Comparable projects were also undertaken in Europe and Asia. See Turnbaugh et al., "Human Microbiome Project."

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respectively. The rest of us comprises bacteria, fungi, archaea, and a few animals invisible to the naked eye.

Scientists interested in this microbiome present the human as a superorganism, accommodating, infected, and kept alive by diverse microbes in dynamic ecologies.[2] Once feared as universally pathogenic, microbes are now ascribed central roles in the performance and maintenance of a healthy body. Stefan Helmreich writes of a general "microbiomania" that has gripped popular science.[3] Microbes have been linked to the successful functioning of our metabolic, immune, and endocrine (hormone) systems, and there is growing interest in how they shape mood and cognition.[4]

This figure of *Homo microbis* queries the coherence of the modern human,[5] understood as an individual and ontologically separate island.[6] It suggests that being human is a multispecies achievement, dependent on the "corporeal generosity"[7] of microbial life. Anxieties have been expressed that the human superorganism is degrading. "Missing microbes,"[8] we are told, make us vulnerable to "epidemics of absence."[9] These changes have been linked to dramatic recent increases in allergy, autoimmune, and inflammatory diseases, while novel internal ecologies marked by microbial dysbiosis create opportunities for the emergence of pathogenic superbugs.

To make matters worse, many of these new diseases have been linked to excesses of modern hygiene. Archetypal modern developments, such as urbanization, antibiotics, cesarean sections, and sewage and water treatment, have all been associated with shifts in the microbiome.[10] There is a growing sense that antibiotic efforts to purify the human by rationalizing, simplifying, and eradicating nonhuman life can be as pathogenic as situations of microbial abundance.

As a consequence, nascent therapeutic efforts are emerging that seek to reengineer internal ecologies, securing the human through probiotic, or what Heather Paxson terms "post-Pasteurian," forms of "microbiopolitics."[11] These involve careful processes of "controlled decontrolling,"[12] using microbes to reorganize ecologies to secure desired systemic properties. Examples include bacteriotherapies like fecal transplants to shift antibiotic bacteria[13] and vaginal seeding to replicate birth canal bacterial colonization

2. See, for example, Turney, *I, Superorganism*.

3. See Helmreich, *Sounding the Limits of Life*; and Paxson and Helmreich, "Perils and Promises of Microbial Abundance."

4. Smith, "Tantalizing Links."

5. Helmreich, *Sounding the Limits of Life*.

6. For discussions see Hird, *Origins of Sociable Life*.

7. Diprose, *Corporeal Generosity*.

8. Blaser, *Missing Microbes*.

9. Velasquez-Manoff, *Epidemic of Absence*.

10. Blaser and Falkow, "What Are the Consequences?"

11. Paxson, "Post-Pasteurian Cultures."

12. See Keulartz, "Emergence of Enlightened Anthropocentrism."

13. Fecal transplants have been the subject of a great deal of popular interest. See Velasquez-Manoff, "Should We Bank Our Own Stool?" Several citizen science projects are now developing do-it-yourself guides and reservoirs of donor feces. See, for example, www.thepowerofpoop.com.

for babies born by cesarean section.[14] They encompass various paleo, pro-, and prebiotic diets designed to work on the gut microbiome[15] and novel personal and domestic hygiene products that actively seed the skin and built environment with stable colonies of good bacteria.[16]

This article contributes to nascent investigations of the implications of the emergence of *Homo microbis* and post-Pasteurian modes of microbiopolitics for multispecies studies. It focuses on helminthic therapy, the controlled (re)introduction of (what are commonly termed) parasitic worms into human bodies to tackle allergies and inflammatory and autoimmune conditions.[17] While programs to deworm the world continue apace in the rural Global South,[18] a growing number of Northern citizens[19] and scientists have recast some helminths as "gut buddies"[20]—salutary symbionts capable of recalibrating dysfunctional bodily relationships. Clinical trials are under way,[21] but these have been overtaken by a burgeoning "hookworm underground."[22] This online community links patients, researchers, and advocates who share and sell animals, equipment, and expertise.[23]

In telling the story of gut buddies, this article is structured in two sections. I first introduce helminths and helminthic therapy, tracing the visceral, multispecies vectors, cycles, and assemblages through which people are differentially entangled, disentangled, and reentangled with helminths. The second section analyses these entanglements with reference to literature on the science and politics of (auto)immunity. It situates helminth science in the vanguard of new ways of conceiving immunity. Scientists working on helminths expand upon binary, martial models of immunity as the defense of the self to consider immunity as tolerance, recruitment, and creative experimentation with microbial symbionts. I trace how immunity with gut buddies is enacted in contrasting multispecies assemblages that illustrate communal and immunitarian characteristics of contemporary biomedicine. In conclusion the article reflects on the character of these forms of post-Pasteurianism and suggests that the probiotic relations of helminthic therapy offer new ways of thinking companionship and hospitality as more-than-human, but not posthuman, achievements.

14. Molloy, "Mothers Facing C-Sections."

15. For some popular works, see Pollan, *Cooked*; and Sonnenburg and Sonnenburg, *Good Gut*.

16. Examples include www.motherdirt.com and www.pro-b.co.uk.

17. For an introduction, see Velasquez-Manoff, *Epidemic of Absence*.

18. For an overview, see Hotez, *Forgotten People, Forgotten Diseases*.

19. Interest seems to have grown in the last decade. A recent survey estimated that six thousand to seven thousand people are currently self-treating with helminths. See Cheng et al., "Overcoming Evolutionary Mismatch."

20. This is the title of the blog authored by one hookworm user: gut-buddies.com.

21. For a review, see Wammes et al., "Helminth Therapy or Elimination."

22. I take this phrase from Velasquez-Manoff, *Epidemic of Absence*.

23. The article draws on review of scientific publications, coupled with ethnographic research with users and providers of helminthic therapy. This involved interviews with key informants and observation and participation in discussion forums and other social media.

Entangling with Worms

A political ontology of entanglement (and disentanglement) has emerged as something of a leitmotif in recent work in multispecies studies, especially in work concerned with human and animal disease.[24] Entanglement describes a world that has never been modern, human, or populated by discrete individuals. Instead it figures humans, animals, and other nonhumans as components of dynamic, nonlinear assemblages in constant processes of mutual becoming. It offers an ontology that attends to the commonplace interspecies exchange of microbiota, viruses, and genetic material while critically interrogating the political ecologies and biopolitics through which different lives are ordered, secured, and abandoned. Advocates are optimistic that an attention to the inevitability of entanglement will help enrich an ethic of living well with nonhuman others.

There has been little examination of the types of deliberate *re*entanglements that feature prominently in this story. In this and subsequent sections I develop this work by tracing the historical (dis)entanglements of humans and helminths that led to the recent emergence of helminthic therapy. Humans evolved and most still largely live in a "wormy world."[25] Corporeal companionship with a range of helminths has been a common part of our species history. Parasitologists have recorded more than three hundred species of helminths that live in humans. Many of these are rare or accidental, but about ninety species are commonly found in human bodies.[26] Few helminths are host specific. Instead, many of our parasites are zoonotic—transmissible between humans and other vertebrate animals.

Helminths have three main life-cycle stages: eggs, larvae, and adults. Adult worms infect definitive hosts (those in which sexual development occurs), whereas larval stages may be free-living or parasitize invertebrate vectors and intermediate hosts. After infection, larvae grow, molt, mature, and then produce offspring, which are voided to infect new hosts or to reinfect the original host. The four main modes of transmission by which helminth larvae infect animals (including humans) are fecal-oral, transdermal (through the skin), vector-borne (e.g., via a snail), and predator-prey (e.g., by humans eating pork).[27] In short, there are myriad diverse and intimate ways in which helminths entangle us with other life forms and ecologies, and these form part of a wider set of vectors through which we are (dis)entangled with our microbiota.

For a more detailed illustration, we can look at human hookworm (*Necator americanus*), which is currently the most popular of the four helminth species subject to reworming.[28] Paleoparasitologists believe that humans acquired hookworm about twelve

24. For a review, see Nading, "Humans, Animals, and Health."

25. Stoll, "This Wormy World."

26. Cox, "History of Human Parasitology."

27. Much of this overview is taken from the Australian Society of Parasitology's website at parasite.org.au/para-site/contents/helminth-intoduction.html.

28. Other species used for helminthic therapy include human whipworm (*Trichuris trichiura*), which has humans as a definite host but can be taken orally. Some human helminth clinical trials have used pig whipworm

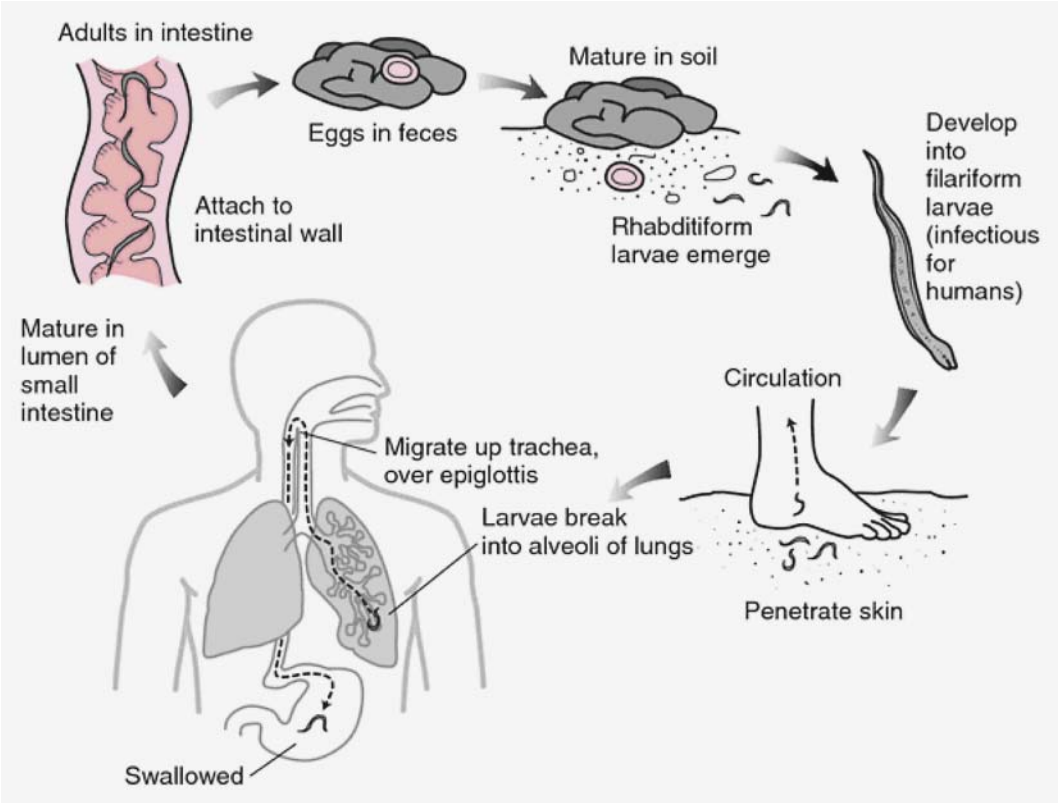

Figure 1. Life cycle of *Necator americanus*. Image from Public Health Image Library, Centers for Disease Control and Prevention (phil.cdc.gov/)

thousand years ago as a result of our increasingly intimate relationships with dogs.[29] This worm is now primarily found in humans and remains one of the world's most common parasitic helminths.[30]

The life cycle of the hookworm is shown in figure 1. Humans first acquire hookworm when the infective larval stages penetrate through the skin. This generally happens between the toes of a bare foot in contact with the soil. Deliberate inoculation involves applying larvae in a bandage to the upper arm. After entering the host, the larvae migrate through the blood vessels to the right side of the heart and then to the lung. They break out of the lung capillaries and ascend the throat where they are coughed and swallowed. From here they enter the gastrointestinal tract and develop into their adult stage. This normally takes about four days, at which point the host may

(*Trichuris suis*), which is genetically related to the human whipworm. *T. suis* ova (or TSOTM) are produced commercially from the feces of pathogen-free pigs, living and dying in laboratory conditions. Biome Restoration sells the cysticercoids (or larval stage) of the rat tapeworm (*Hymenolepis diminuta*), which are harvested in their laboratory from a grain beetle (*Tenebrio molitor*), their intermediate host.

29. Palmer, "Migrant Clinics and Hookworm Science."

30. Schneider et al., "History of Hookworm Vaccine Development."

experience coughing, the flare-up of rashes, fatigue, diarrhea, cramping, nausea, and vomiting.[31] Some users report that a few days later, the worms may cause a "bounce": a sudden improvement in symptoms and a strong sense of calm, focus, happiness, and lightheartedness.

After about three weeks, the hookworms take up residence and feed on blood from the walls of the intestine. The patient's health then often deteriorates. In a therapeutic context, worms start to work, and symptoms begin to ease, at around twelve weeks. By week 20 the worms are usually well established, and by week 45 the worms and body reach equilibrium—providing there is no further infection. Hookworms live in the human intestine for an average of three to ten years. Each female produces thousands of eggs daily, which exit the body in feces. When deposited in soil (or equivalent artificial growth medium) with adequate warmth, shade, and moisture, the eggs hatch within hours and give rise to new larvae. And so the cycle continues.[32]

Unlike other forms of life in us (viruses, bacteria, protozoa, and fungi), helminths need to reproduce outside their definite host. Hookworms tend to develop slowly in vertebrate bodies. When people use toilets connected to sewage treatment systems, there is little risk of hookworms returning to the wild. However, high worm loads can accumulate in political-ecological conditions marked by poor sewage treatment, which leads to high exposure risk. As these conditions are often coupled with poverty, poor nutrition, and other diseases, helminths can cause significant morbidity.[33] Deworming was a major public health priority for the Rockefeller Foundation and then the World Health Organization during the twentieth century,[34] and these efforts have been stepped up under recent initiatives to address "neglected" tropical diseases.[35]

Deworming programs seek to intervene in the life cycle of the target helminth, disentangling its vectors for infection to secure the human body. Hookworm eradication requires investments in sanitation and footwear, coupled with the development of antihelminthic drugs. The former prevent transdermal infection, while the latter purge the body of existing parasites. However, sanitation projects are expensive, and the regular distribution of drugs is politically challenging. Worms also develop drug resistance, and there has been limited investment in developing alternatives now that worms have disappeared from more affluent Northern markets. New drugs appear only as spin-offs from developments in the more lucrative field of antihelminths for domestic and

31. I take this experiential information from a document titled "Timeline following Inoculation with Hookworm," hosted on one of the main support group websites, at www.foodsmatter.com/natural_medicine_comp_therapies/helminthic_therapy/articles/hookworm-timeline-03-12.pdf (accessed March 9, 2016).

32. This description is largely derived from Brooker, Bethony, and Hotez, "Human Hookworm Infection."

33. Hotez, *Forgotten People, Forgotten Diseases*.

34. Farley, *To Cast Out Disease*; Anderson, *Colonial Pathologies*; Palmer, "Migrant Clinics and Hookworm Science."

35. The political geography of hookworm presence and absence illustrates stark political ecological disparities. I discuss deworming and the broader geographies and political ecologies of hookworm eradication and reintroduction in more detail in Lorimer, "Living Well with Parasitic Worms."

agricultural animals.[36] In the prevalent biopolitical regimes of pharmaceutical capitalism, the health of pets and livestock is worth more than that of many people in the majority world. Recent efforts, funded by the Gates Foundation, focus on the development of a hookworm vaccine: a one-shot solution to ensure permanent helminth absence.[37]

Investments in deworming have driven steady declines in the incidence of helminth infection in the Global North and in urban areas of the Global South.[38] However, the desirability of wholesale helminth eradication and human disentanglement has begun to be questioned by a growing body of scientific theory, evidence, and vernacular practice. Epidemiologists have noted for some time an association between general declines in infection and the increase in susceptibility to certain autoimmune and allergic diseases.[39] In 1989 David Strachan offered a hygiene hypothesis to account for these broad trends.[40] This has been refined in recent years into the old friends hypotheses.[41] These suggest that changes in the composition of the human microbiome and the microbial ecologies with which people evolved unsettle basic bodily systems that enable processes like metabolism and immunity.

These hypotheses have informed a wide range of laboratory research using animal models (largely gnotobiotic mice) whose microbial composition is known and controlled. Experiments using murine helminths, comparable to those of humans, try to simulate and explain the links between de- and reworming and the incidence of allergic and autoimmune disease. Wammes and colleagues explain how these mouse experiments "provide strong evidence that helminths can not only downregulate parasite-specific immune responses but also modulate autoimmune and allergic inflammatory responses and improve metabolic homoeostasis."[42] A number of clinical trials have been undertaken first to test the safety of reintroducing helminths into human patients suffering particular autoimmune conditions and then to explore its effects. These trials have shown that these patients can host a modest number of worms with no significant side effects or risk of wider infection. The results of these trials have to date been mixed and inconclusive, and further studies are under way.[43]

In parallel with these scientific developments and in part in frustration at their slow progress, a variety of patients, citizen scientists, and health providers have been experimenting with helminthic therapy. One of the early advocates was the British

36. Hotez et al., "Human Hookworm Vaccine."

37. Schneider et al., "History of Hookworm Vaccine Development."

38. Parker et al., "Prescription for Clinical Immunology."

39. Bach, "Effect of Infections." For specific research on helminths, see Flohr, Quinnell, and Britton, "Do Helminth Parasites Protect against Atopy and Allergic Disease?"

40. Strachan, "Hay Fever, Hygiene, and Household Size."

41. Rook, "Helminths, Immune Modulation, and the Hygiene Hypothesis"; Hanski et al., "Environmental Biodiversity."

42. Wammes et al., "Helminth Therapy or Elimination," 1150.

43. Ibid.

entrepreneur Jasper Lawrence, who was a participant in one of the first hookworm clinical trials in the early 2000s.[44] He found they significantly helped his hay fever. After losing his worms, he traveled to rural Cameroon to walk in some latrines in the hope of picking up replacements. He got the wrong worm, but after a further trip to Guatemala he established his own worm colony. He started a company breeding, selling, and infecting his worms into paying customers. Because it is currently illegal to bring hookworm into the United States outside a human body or to distribute them within the country, Jasper initially based himself in Mexico. It is perfectly legal to cross the border to Tijuana to get infected. At the time of writing, there were four online commercial providers of hookworm, who will send larvae via mail and provide follow-up support to anyone outside the United States.

The driving energy for the subsequent growth of helminthic therapy comes from a vibrant network of online support groups, which link together a globally disparate community that operates independently of scientific researchers and commercial providers. These groups are powered by a small number of early adopters of the therapy happy to share their experience, expertise, and enthusiasm with those interested in experimenting. They have worked long, unpaid hours to collate information into a set of online handbooks, to provide news, and to answer questions. Acting as moderators, these individuals also facilitate and police the sociabilities of this heterogeneous and diffuse community.

Empowered by online resources and their own experiments, some users have learned to grow their own hookworms and other helminths. They use animals originally purchased from commercial providers or those sourced from participation in clinical trials. Some have cobbled together readily available domestic technologies to make their own laboratories. Detailed incubation protocols circulate containing instructions on how to combine soil, heat rocks marketed for reptiles, and various other household chemicals to create surrogate ecologies for incubating and nurturing worms. Making use of cheap microscopes and library images, they harvest and isolate new stock from their feces and count larvae before self-infecting.

Entanglement here involves awkward forms of care,[45] a novel ecosystem of mundane technologies, and a spatially diffuse online network of suppliers, experts, and supporters. This network provides a reserve of hookworm stock that can be called upon in the (all too frequent) case of worms dying or going missing. Incubators are happy to supply others in a multispecies gift economy, though their incubation protocols, advice, and gifts are frequently prefaced with legal disclaimers. There is a high level of scientific expertise within this group, which includes a number of laboratory technicians and practicing microbiologists. These assemblages for helminthic therapy thus perform ecologies. They replicate (and terminate) life cycles and simulate infection vectors in

44. Lawrence's story is reported in more detail in Velasquez-Manoff, *Epidemic of Absence*.

45. Ginn, Beisel, and Barua, "Flourishing with Awkward Creatures."

various professional and makeshift laboratories, affording control over how, when, where, and to what degree patients "hook up" to their gut buddies.

Rethinking Immunity for a Wormy World

We can begin to specify some of the practices and political ecologies of human-helminth (dis)entanglements by drawing on a range of existing literature on immunity. This literature cuts across the humanities and the social and natural sciences, examining shifting scientific understandings of immunity and the ways in which these draw upon and come to inform broader social norms and political practices. Many authors agree that the modern biomedical concept of immunity is premised on a series of binary, martial metaphors in which an immune system works to defend a stable, individual, and essential human self from alien, invading, nonself others.[46] Historians attribute this martial understanding to the emergence of immunology at the end of the nineteenth century, a period characterized by the fight against infection and the prominence afforded the germ theory of disease.[47] Germ theory linked the incidence of disease to the presence of specific microorganisms. Immunity came to describe defense against germs.

Critics have traced the ways in which such conceptions of immunity came to shape biopolitical practices governing human and nonhuman life to secure specific ideas of what is normal and what is pathological.[48] They explain how the figure of the normal self was frequently bound to colonialism, capitalism, and patriarchy. Such norms were also tied to antibiotic models of hygiene—perhaps best exemplified by Pasteur and a Pasteurian approach to public health.[49] Historians and contemporary commentators note the incidence and persistence of binary, martial conceptions of immunity in programs for helminth control and eradication. Warwick Anderson argues that twentieth-century sanitation projects often involved practices of "excremental colonialism": a somewhat obsessive, racialized, and highly moralized focus on hygiene among foreign doctors and administrators targeting the management of human waste to prevent cycles of reinfection.[50] Others have noted how some helminth drug delivery programs that are premised on the imposition of Western models of individual rational subjectivity may be ignorant of local norms and reductionist in the face of political and ecological complexities and injustices.[51]

The pathological consequences of the success of such biopolitical projects in disentangling people from helminths and other microbiota are the central concerns of the hygiene and biome depletion hypotheses. Table 1 offers a list of hygiene practices

46. For a comprehensive account, see Cohen, *Body Worth Defending*; or Martin, *Flexible Bodies*.
47. Tauber, "Immune System and Its Ecology."
48. Cohen, *Body Worth Defending*; Haraway, "Biopolitics of Postmodern Bodies."
49. Latour, *Pasteurization of France*.
50. Anderson, "Excremental Colonialism."
51. Geissler, "'Worms Are Our Life'"; Palmer, "Migrant Clinics and Hookworm Science."

Table 1. Hygiene practices understood to negatively affect human ecology

Change	*Consequence*
Clean water	Reduced fecal transmission
Increase in cesarean sections	Reduced vaginal transmission
Increased use of preterm antibiotics	Reduced vaginal transmission
Reduced breastfeeding	Reduced cutaneous transmission and changed immunological environment
Smaller family size	Reduced early life transmission
Widespread antibiotic use	Selection for changing composition
Increased bathing, showering, and use of antibacterial soaps	Selection for changing composition

Source: Adapted from Blaser and Falkow 2009, 889.

understood to have deleterious consequences on the human microbiota, abbreviated from a paper published by two high-profile microbiologists.[52] The listed changes stem from innovations that are often heralded as fundamental to being developed and modern.

No one is advocating giving up on the real improvements these interventions have brought in the management of infectious disease (at least in certain parts of the world). But anxiety about these changes speaks of a wider crisis in the martial, binary understanding of immunity and the scientific and health care paradigms it informs.[53] One group of immunologists goes so far as to suggest that "practices of industrialized culture aimed at reducing infectious disease have apparently created the single most potent element destabilizing the immune system in hundreds of millions of humans."[54]

New research on the relationships between helminths and autoimmunity is in the vanguard of a paradigm shift in conceptions of the immune system. As Mathilde Versini and colleagues explain:

> It is worth noting that helminthes [*sic*] have co-evolved with their host for millennia; their goal is not to kill their host but to survive as long as possible by creating a state of tolerance. To achieve this, helminthes are able, through various mechanisms, to finely modulate the host immune system to prevent an activation that may lead to their elimination, while not causing too deep an immunosuppression which would cause the host to die from infection. This immunomodulation, by avoiding an excessive activation of the immune system, contributes to host protection against inflammatory disorders. . . . It is becoming apparent that these parasites are acting simultaneously at all levels and on the different key cellular players of the immune system establishing a real network aiming to promote a tolerant environment. Thus, helminthes hamper immune response to

52. Blaser and Falkow, "What Are the Consequences?"

53. See discussions in the collection of workshop papers from the Forum on Microbial Threats, *Ending the War Metaphor*.

54. Parker et al., "Prescription for Clinical Immunology," 1195.

> ensure their own survival and simultaneously protecting the host against the occurrence of chronic immune-mediated conditions by limiting the development of inflammation and autoimmunity.[55]

Understood this way, parts of the immune system are not at war with invaders. Instead they are involved in continuous processes of communication, modulation, and diplomacy. We learn that worms enter into a "continuing dialogue"[56] with the human immune system, establishing a "helminth-induced immune regulatory environment"[57] or "network"[58] to enable permanent residence. This is a world of tolerance[59] in which "intimate biochemical chatter"[60] enables forms of interspecies communication.

Such scientific accounts of interspecies communication and diplomacy agree with how helminths (as gut buddies) are discussed among patients and providers. One company offers a twofold account of beneficial work done by their helminth: worms initially serve to calibrate the immune system, helping its development, especially among young children, and then work to exercise adults' immunity, keeping the immune system sufficiently busy or distracted to avoid its turning against itself.[61] The hookworm underground, as performed in online support groups, presents a range of immunological epistemologies. Recent scientific developments are mobilized in support of lay immunologies akin to those mapped in writings on probiotic and raw milk food cultures.[62] Discussions of worm therapy interface with the probiotic enthusiasms outlined in the introduction. These include other forms of biotherapy, various paleo diets, and a reinvention of early twentieth-century personal and domestic hygiene practices. Earthy knowledges of baking, pickling, and herbalism are well regarded.[63]

We can link these ideological shifts and changing cultural commitments to existing work that documents the emergence of new metaphors of immunity in efforts to understand and tackle autoimmunity. For example, Scott Gilbert, Jan Sapp, and Alfred Tauber suggest that symbiotic conceptions of immunity show an immune system that not only tolerates nonself components but also is engaged in the active recruitment of desirable microorganisms. They depict the immune system managing its microbial (dis)entanglements with two arms. The first arm is the body's armed forces; the second, its passport control: a regulatory network that "has evolved to recognize and welcome those organisms that help the body."[64] David Napier talks of an immune system

55. Versini et al., "Unraveling the Hygiene Hypothesis."
56. Allen and Maizels, "Diversity and Dialogue," 385.
57. Helmby, "Helminths and Our Immune System," 122.
58. Wammes et al., "Helminth Therapy or Elimination."
59. For a discussion of tolerance as a metaphor for immunity, see Anderson, "Tolerance."
60. Sachs, *Good Germs, Bad Germs*, 12.
61. See Biome Restoration's website at www.biomerestoration.com.
62. See, for example, Enticott, "Lay Immunology, Local Foods, and Rural Identity."
63. The broad ethos of North American incarnations of this cultural movement is conveyed in recent writings by Michael Pollan. See, for example, Pollan, *Cooked*; and Pollan, "Some of My Best Friends Are Germs."
64. Gilbert, Sapp, and Tauber, "Symbiotic View of Life," 332.

permitting "creative attempts to engage risk at the borders of self,"[65] actively seeking communication and entanglement as a learning process. Similar metaphors shape the lifestyle experiments for cultivating tolerance through deliberate exposure to potential allergens that are reported and advocated by Emily Martin and Richard Cone.[66]

A great deal of scientific research in this new paradigm focuses on understanding how helminths are able to regulate and downgrade the host immune system. Microbiologists are beginning to trace the complex interactions among human host, helminths, and resident microbiota (especially bacteria).[67] There is a growing sense that helminths manipulate the microbial population of their host for their own ends.[68] Applications of this research have focused on antibiotic techniques for eradicating worms by killing their bacterial symbionts[69] as well as more probiotic experiments seeking to understand helminths as keystone species capable of engineering entire bodily ecologies.[70] This figure of the helminth as a keystone species has some fairly profound implications for humanist conceptions of agency and autonomy. It appears that helminths are capable of reorganizing our bodily ecologies in ways that not only affect our "gut feelings" of immunity and metabolism but also might shape the more refined processes of mood and cognition.[71]

In this understanding, human and worm bodies "learn to be affected" by each other through an ongoing molecular exchange.[72] The ethology of these affectations can be distinguished from much existing work in this part of multispecies studies, which has tended to focus on becomings and attunements between visible and relatively large and discrete beings. The story of worms allows us to rethink accounts of learning to be affected through the figure of *Homo microbis*. Those learning to live with and care for their gut buddies talk of "care-full" management of their bodily ecologies to nurture their symbionts. Diet, medicine, exercise, and even environmental exposures are managed experimentally to protect worms and meet their needs. One hookworm user drew an analogy with her care-full bodily practices while pregnant.[73] Many hookworm users live with chronically dysfunctional guts and hypersensitive immune systems. They have developed means of articulating the sensibilities, temporalities, and emotions of gas, diarrhea, and other disturbing dynamics of fecal movements. They share the heightened affective sensibilities of those whose bodies do not work properly or will not remain in

65. Napier, "Nonself Help," 131.

66. Martin and Cone, "Immune System."

67. See, for example, Bilbo et al., "Reconstitution of the Human Biome."

68. Hayes et al., "Exploitation of the Intestinal Microflora," 1394.

69. See, for example, Coulibaly et al., "Randomized Trial of Doxycycline."

70. Parker et al., "Prescription for Clinical Immunology."

71. Schmidt, "Mental Health."

72. Despret, "Body We Care For," 113.

73. Pregnancy (as the tolerance of nonself in self) has long served as something of an ontological challenge to theories and theorists of immunity grounded in binary and martial concepts. See discussion in Anderson and Mackay, *Intolerant Bodies*.

the background. In their intense personal affective ecologies, worms bring lethargy, hope, relief, and often disappointment.

Figuring worms as needy keystone species calls attention to the interests of the animals that are made subject to de- and reworming programs. It is likely, though little known, that the twentieth century saw dramatic declines in helminth biodiversity. The extinction of hosts sees the extinction of parasites and symbionts, and there has been little interest in parasites in wildlife conservation, captive animal management, and species reintroduction projects.[74] Meanwhile the development of antihelminth drugs will have eradicated significant numbers of domestic animal parasites, such that some domestic animals have begun experiencing comparable outbreaks in autoimmune disease. Nascent programs are under way to conserve human microbial diversity in biobanks,[75] though understandably there is little enthusiasm for conserving free-ranging populations of helminths. Others have suggested domesticating worms through genetic modification both to improve their salutary properties and to tame their infectious agencies.[76] Little is known of the shifting behaviors and sensibilities of the worms themselves as they learn to be affected in taking residence in different bodily ecologies whose molecular and microbial constituents are unused to their presence. Perhaps they struggle with an overactive immune network primed to destroy? Perhaps they are welcomed by microbes keen to communicate and experiment?

What emerges in this story is an ecological model of immunity as involving a multispecies community—maintaining stable systemic states through reactive defense, continuous internal dialogue, and the proactive recruitment of, and experimentation with, new microbes. The immune system both is primed to respond to undesired arrivals and can be unsettled by the absence of a familiar conversant. Securing the immunomodulation benefits of helminthic therapy entangles patients in an immune network that extends well beyond the human body. It can include laboratory animals: the pigs, rats, and beetles used to farm helminths and the mice that are used to test their effects in the lab. It also requires a diverse technological ecology of laboratory and other more mundane equipment, enacting particular geographies through postal services and the virtual texts and interactive possibilities of the Internet. It is through these networks that patients engage in creative experiments in deliberative helminth recruitment. They source, self-infect, and discard organisms in ways that extend Gilbert and colleagues' and Napier's metaphors of recruitment and experimentation beyond the body to expand those forms of sociability at play in securing health.

Hooking up with helminths as gut buddies thus entangles users in sociabilities configured within contrasting political ecological formations. In the hookworm underground we find people sharing and storing worms and offering care, expertise, and

74. Dougherty et al., "Paradigms for Parasite Conservation."

75. Barzegari, Saeedi, and Saei, "Shrinkage of the Human Core Microbiome."

76. See Parker et al., "Prescription for Clinical Immunology."

technology in a community configured around a multispecies gift economy. Here worms are held in common. Most of the commercial providers of helminths are nonprofit, pricing their worms to cover production costs. This model of community would seem to bear many of the hallmarks of that desired by the biophilosopher Roberto Esposito in his recent writings developing an affirmative mode of biopolitics that runs counter to the immunitarian logics of modern, capitalist life.[77]

In contrast, much scientific investment, research, and development on helminths and immunity focuses on finding means for privatizing their immunosuppressant properties. Here there is much excitement about "harnessing the helminth secretome for therapeutic immunomodulators," as the title of one paper puts it.[78] Scientists involved in decoding the hookworm genome speak of a veritable pharmacopoeia of synthetic (and thus patentable) molecules that will become available for a new phase of drug development. New forms of "lively capital"[79] are expected to ensue (somewhat paradoxically) from drugs directed toward either helminth eradication or the replication of their immunosuppressant properties.[80] While these developments are nominally about creating safe, hygienic, palatable, and convenient means of delivering helminths' benefits, they also work to overcome the legal challenges of privatizing a living organism that is currently classified as a dangerous pathogen. These interventions would enable the commodification of what the hookworm underground currently holds in common. They are contested and resisted by scientists concerned with biome restoration and many members of the hookworm underground.[81] There is a general concern that profit-centered efforts to privatize the hookworm secretome may undermine patient-centered benefits already accruing in helminthic therapy.

Probiotic Multispecies Relations

The figure of *Homo microbis* depicts humans as superorganisms, entangled with other animals and bacteria in a range of multispecies economies.[82] We learn of the fundamental dependence of our basic bodily systems on symbionts, our continued vulnerabilities to parasitic and pathogenic infection, and the deleterious consequences of missing microbes. The human superorganism emerges as an unstable and permeable ecology, tipped toward undesirable dysbiosis by situations of both intense abundance and rapid decline and absence. A great deal of basic science is still to be done in this area, and many of these understandings are tentative and will no doubt shift in the coming years.

77. Esposito, *Immunitas*. For a useful overview see Campbell, "Bios, Immunity, Life."

78. Ditgen et al., "Harnessing the Helminth Secretome."

79. Rajan, *Lively Capital*.

80. Tang et al., "Genome of the Human Hookworm"; Navarro, Ferreira, and Loukas, "Hookworm Pharmacopoeia."

81. Biome Restoration (www.biomerestoration.com), one company selling helminths, is heavily informed by the work of William Parker. See Parker et al., "Prescription for Clinical Immunology"; and Parker and Ollerton, "Evolutionary Biology and Anthropology."

82. Helmreich, *Sounding the Limits of Life*.

Nonetheless, in conclusion I would like to return to my opening discussion to explore what the story of hookworm therapy and disease contributes to engagements by multispecies studies with the microbiome. I focus in particular on how this work helps specify a post-Pasteurian mode of living with microbial life.

Even the most gung ho advocates of microbial rewilding are post- rather than anti-Pasteurian. In Paxson's terms, they "work hard to distinguish between 'good' and 'bad' microorganisms and to harness the former as allies in vanquishing the latter. Post-Pasteurianism takes after Pasteurianism in taking hygiene seriously. It differs in being more discriminating."[83] Advocates and practitioners of helminthic therapy do not want to give up on the real gains to health that modern hygiene has delivered, nor do they want to undermine efforts to extend these benefits to the large parts of the world where they remain absent. Instead they are involved in careful and reversible experiments to address the absences and perceived excesses of contemporary hygiene.

These experiments contribute to ongoing efforts to develop nuanced, relational, and contextual understanding of the exchanges that take place in human-microbial relations.[84] Immunologists and therapists suggest that recognizing the salutary role of some microbiota in regulating the human immune system calls into question the common, blanket description of helminths as parasites. In many historical and contemporary circumstances it is clear that helminths are parasitic, but in managed reentanglements hookworms also figure in three more affirmative guises (at least from a human perspective). First, both clinical scientists and therapists describe hookworms taken in controlled quantities and conditions as symbionts or, more specifically, mutualists: organisms that flourish in and confer benefits upon their host. Second, hookworms achieve this mutualistic status by acting as a keystone species capable of reorganizing dysfunctional microbial ecologies. Third, future probiotic imaginaries feature helminth domesticates, modified to best deliver their symbiotic potentials. As this article begins to make clear, there are important geographies and political ecologies that shape when, where, and for whom helminths relate in these different guises.

There are also important ethical and political dimensions to the reinvention of helminths as gut buddies. The lay immunologies of practitioners of microbiome restoration demonstrate ambivalence about some dimensions of being modern. They express ecological models of immunity in community similar to those that can be derived from the writings of thinkers like Esposito. But their grounds for microbial hospitality emerge from the protection of the human subject. While Esposito's writings tend to affirm an undifferentiated and posthuman life,[85] here worms are strategically employed as tools for the job of securing individual health. These experiments do not seek to deliver a posthuman subject, where the human is dissolved into a set of symbiotic exchanges and microbial flows; rather, they remain firmly targeted at securing the human—with

83. Paxson, "Microbiopolitics," 118.

84. See, for example, Rose, "Multispecies Knots of Ethical Time"; and Bull, "Between Ticks and People."

85. For a discussion of Esposito's conceptions of immunity and biopolitics, see Wolfe, *Before the Law*, 87–105.

varying normative connotations—in the face of the vulnerabilities of microbial presence and absence.

The story of worms therefore intersects with and offers an important and interesting twist to the emerging interest in multispecies studies with questions of hospitality and companionship in the macrobiome. Here companion species are quite literally those with whom we eat and upon whose agencies digestion depends, necessitating a more expansive and intimate understanding of multispecies gift economies.[86] In the case of worms, hospitality starts on the inside, and being a good host involves being infected well. Participants in the hookworm underground care for their worms as friends. But these are friends without a face, sensed through an invisible corporeal interface.[87] Hookworm users are willing to make bodily sacrifices to preserve their worms' vitality, but only to the extent that the worm functions well as a keystone agent. There is little concern for the independent welfare of the individual worm, as some express for their mammalian pets, or for the wider flourishing of free-ranging helminth species, as some express for wolves or tigers.

Contrary to the posthumanist hopes for a decentered human that can be found in some enthusiastic receptions of the human microbiome in multispecies studies,[88] here the human remains central to the multispecies ethics performed, albeit the human in a fragile, unstable, and untrustworthy form. The central concern is with securing an individual multispecies body or the bodies of close kin and a community of shared sufferers. Securing this human as a multispecies microbial self involves defense, communication, and recruitment, differentiating the good, the bad, and the indifferent in all their microbial diversity. Living well with a stable, background, and unconsidered microbiome is possible only as a result of having a world at home in us. Caring for those without requires attending to those within. Hospitality thus starts at home and involves distinctly painful and awkward acts of care. Becoming hospitable involves selective openings and entanglements in a diffuse and more-than-human community of symbionts and their people.

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86. See Rose, "Multispecies Knots of Ethical Time."

87. For an extended discussion of the ethical potential of friendship between humans and nonmammalian animals, see Bingham, "Bees, Butterflies, and Bacteria."

88. See, for example, Sagan, *Cosmic Apprentice*.

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