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Revue d'anthropologie des connaissances

15-3 | 2021
Un tournant microbien ?

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Electronic version
URL: https://journals.openedition.org/rac/25068
ISSN: 1760-5393

Publisher
Société d'Anthropologie des Connaissances

Brought to you by Centre national de la recherche scientifique (CNRS)

Electronic reference
Charlotte Brives and Alexis Zimmer, "Ecologies and promises of the microbial turn", *Revue d'anthropologie des connaissances* [Online], 15-3 | 2021, Online since 01 September 2021, connection on 03 January 2022. URL: http://journals.openedition.org/rac/25068

This text was automatically generated on 3 January 2022.

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> In their very make-up, micro-organisms shed light on precisely how biology is situated, that is, on how humans transform the biological world in which they live and, in so doing, change their own biological make-up. (Lock & Nguyen, 2018, p. 335)

In November 2019, when we submitted a draft for a special issue of this journal dedicated to microbes, we intended to investigate the emergence of a "microbial turn" (Paxson & Helmreich, 2014) occurring in the natural and biomedical sciences and for which the social sciences were attempting to account. We had been struck by current research and publications, intended for non-specialist audiences (Selosse, 2019; Sonnenburg & Sonnenburg, 2017; Yong, 2017) as well as for more strictly scientific audiences, addressing the essential role played in the functioning of ecosystems by "microbes" as beneficial architects of human and animal health. At first glance, this research would appear to suggest a more positive reassessment of the role and nature of microorganisms. Microbes, which had been considered enemies causing the emergence of pathologies, could also become potential allies, both in restoring disturbed ecosystems and in efforts to combat certain chronic or infectious pathologies, thus bearing the promise of the development of new treatments and ecosystem restoration practices (Paxson & Helmreich 2014; 2017). Along with "microbial turn," other expressions such as "post-Pasteurian cultures" (Paxson, 2008), or the "probiotic turn" (Lorimer, 2020) have also been proposed, seeking to capture and name a purported moment of renewal in a number of scientific and lay practices and skills involving microbes, defined in a basic sense as a set of living entities whose common characteristic is that they are invisible to the naked eye.[1] But are these

notions of microbial, post-Pasteurian or probiotic turn really appropriate to describe the new relationships being developed between certain humans and a wide variety of microbes? And if so, what relationships, and with which "microbes"? The category known as "microbes" indeed contains a prodigious variety of microorganisms: bacteria, viruses, yeasts, protists, amoeba, planarians, archea, even some algae and fungi,[2] for each of which we also have multiple further classifications.[3] So what exactly is it that we really mean when we refer to "microbes"?

Then came the Covid-19 pandemic. It was a shocking reminder that in certain circumstances some microbes are capable of seriously shaking up the routine operation of our societies, and suddenly interrupting many people's lives. It also highlighted the fact (now firmly anchored in a vast literature in the humanities and social sciences) that humans are not the only ones that make up society (Latour, 1984; Harper, 2019; Snowden, 2020). A multitude of living beings and various phenomena participate in the making of the worlds in which we live. And, as SARS-CoV-2 shows us, microbes have their place in them as well. Conversely, the pandemic has also highlighted the impact of political and economic choices on the generation, circulation and transformation of microbes (for example, Hinchliffe *et al*., 2021). But is the pandemic a good lens through which to analyze the potentially new relationships developing between humans and microbes? It is probably too early to tell. Nevertheless, it did clearly emphasize the persistence of the deeply contentious and warlike aspects of some of our relationships with microbes, and the way they continue to guide public health policies and the management of pandemics in general (Bensaude-Vincent, 2020; Brives, 2020). Covid-19, indeed, is still essentially considered identical to the virus, and approaches taken to the management of the pandemic mainly seek to interrupt its spread, either by placing populations under lockdown, ordering the use of "safety measures", the massive use of hygiene and cleaning products, or by changing the immunity of populations via vaccination. All this has tended to largely relativize the scope and content of this "microbial turn", or at least would lead one to observe first and foremost that it does not seem to apply across the board to all relationships between humans and microbes.

If we find these expressions to be of interest, it is only proper that we should investigate the matter and put the disruption and novelty they seek to describe into context. Some of the contributions to this issue discuss their relevance directly (de Guglielmo 2021; Demeulenaere & Lagrola 2021), but all highlight the plurality and ambivalence of the relationships maintained, sometimes over the long term, between humans and microbes. Thus, rather than simply adopting these expressions for our own use, this introduction and this issue of the *Revue d'anthropologie des connaissances* seeks to discuss them, to examine what we find relevant about them, and, by pointing out their contributions and their limitations, to expose them to issues that they may tend to neglect. For this purpose, we will first and more precisely discuss what is meant by the notion of the microbial turn by the authors that developed it and the authors associated with it. Once we have made those clarifications, we will seek to discuss these notions and put them into perspective by situating them within the larger context of the social science literature on microbes. This will allow us on the one hand to reengage with a variety of narratives and approaches with regard to human/microbe relationships that preceded this so-called turn, and on the other hand to highlight focal points to monitor in regard to the promises attached to them. In this way we will be able to provide a presentation of the various contributions to this issue and how they contribute to this discussion.

Contextualizing the microbial turn (and its associated expressions)

In 2014, anthropologists Heather Paxson and Stefan Helmreich published an article that mentioned what they called a "microbial turn". This expression was based on previous work done by the two researchers, one of whom had already attempted to apply the notion of "post-Pasteurian cultures" to describe the changes taking place in human/microbe relations in regard to cheese production in the United States (Paxson, 2008). Heather Paxson essentially insisted on the reversal of a negative perception of microbes into a positive one, as well as on the consequent renewal of practices and the play of alliances and collaborations between microbes and the diversity of human actors involved in cheese production. The notion she later introduced, of a "microbial turn," was more multidisciplinary. The concept was intended to reflect, on the one hand, the new attention to which microbes are now being subjected in domains as varied as the natural sciences, dietary practices, and biomedicine, and, on the other hand, to insist on the ecological aspects of the approach to them - in terms of their habitats, relationships and communities. This expression caught on very quickly; it was used in the first history thesis on the subject of the "microbial body," defended by science historian Funke Iyabo Sangodeyi in the same year (Sangodeyi, 2014), and then in the work of geographers Jamie Lorimer (2016; 2017) and Beth Greenhough (2020), as well as in work done by some others (Warren *et al.*, 2020; O'Riordan *et al.*, 2017; etc.).[4] Returning to the notion, Jamie Lorimer then proposed another, even more multidisciplinary concept, embracing a wide range of practices and interventions, including health, food, conservation and land "rewilding" policies, and addressing a bestiary broader than microbes alone, including wolves and parasitic nematodes in particular: namely, the notion of a "probiotic turn." This phrase aimed to "describe human interventions that use life to manage life, working with biological and geomorphic processes to generate forms of human, environmental and even planetary health" (Lorimer, 2020, p. 2 – comparative analysis in this issue). Like the notion of the microbial turn, it is counterposed to modes of management described as antibiotic, and draws attention to ways of renouncing the domination and control of ecologies.

But now let's return more specifically to the "microbial turn." Heather Paxson and Stefan Helmreich define it as follows: this turn,

> taken in recent years by biology... marks... the advent of a newly ascendant model of 'nature,' swarming with organismic operations unfolding at scales below everyday human perception, simultaneously independent of, entangled with, enabling of, and sometimes unwinding of human, animal, plant, and fungal biological identity and community. Microbes are not tokens, as were the late-20th-century reductionist genome and (putatively) carbon-copy clones of the 'age of biological control' (Franklin, 2007; Wilmut *et al.*, 2001, but are rather pointers to a biology undetermined and full of yet-to-be explored possibility. (Paxson & Helmreich, 2014, pp. 167-168).

Here we can point out two characteristics associated with this turn. First, microbes are part of the emergence of a new understanding of "nature," and the microbial scale has started to be seen as pertinent for understanding various phenomena. This point may be similar, for example, to the way the works of biologist Lynn Margulis approached microbes in the 1980s as the living beings par excellence. In those works and in her

collaborative work with atmospheric chemist James Lovelock, she demonstrated the fundamental role of microbes both in the metabolic and regulatory processes of the biosphere and in those which govern the evolution of living organisms (Margulis & Sagan, 1986, see also Sapp, 2009). Likewise, they came to be seen as a sign of the advent of a non-reductionist and undetermined biology, free from the desire for domination and control.

As these authors point out, however, it is not microbes "on their own" that have opened up these new perspectives, but rather a set of "cultural, social, political, and scientific practices that microbes tend to reformat and reshuffle... in unexpected ways" (Paxson & Helmreich, 2014, p. 167). Microbes are neither "good" nor "bad"; indeed they are simultaneously essential and potentially dangerous. This ambivalence is particularly visible in fermentation-related food production practices, upon which the subsistence of many populations greatly depends, and in which there is a renewed interest, at least in Westernized societies: centuries-old practices are now being reinvented, seeking to reintroduce a diversity of relationships, styles, and flavors, as well as increased autonomy in production, all of which had been previously reduced due to the homogenization of food and ecologies by modern industrialization (Tancoigne, in this issue; Demeulenaere & Lagrola, in this issue; Jasarevic, 2015; Chartier, 2021; Davidson & Ransom-Jones, 2021, Rest *et al.,* 2021). It is thus not insignificant that the term "microbiopolitics," coined by Heather Paxson to address regulations on food safety and hygiene and management via everyday actions as well as the moral values underpinning them, was originally introduced in a paper on the subject of cheese production (Paxson, 2012). This ambivalence is reflected in political choices, by the establishment of specific standards aimed at managing the risks inherent in our relations with microbes (for example the establishment of a specific quantity of total microbes/ml as an indicator of the quality of milk for use in cheese production, the consequences of which are studied in this issue in the articles contributed by Demeulenaere & Lagrola and Tancoigne), but also by a shift in the values assigned to uncleanliness and waste (Hird, 2012).

A major change occurred with the development, in the early 2000s, of metagenomics – *i.e.*, of new methods and technologies allowing the sequencing of the genetic content of samples taken directly from a particular environment. This set of techniques has led to a renewed appreciation of the importance of microorganisms in the make-up of environments. What is certain is that now, for the first time, scientists have succeeded in producing data on microorganisms that could not previously be isolated and grown, thus rendering observable a diversity hitherto only suspected.

These techniques have thus contributed to rethinking the different classification criteria of microbes and how they come together, reviving debates around the notion of species.[5] They have also reopened fields of questions regarding interindividual, inter-community and interspecies dynamics, in particular (but not only) relative to our understanding of the mechanisms of evolution (O'Malley, 2014). The rigidity of the barriers between species had already been questioned by the microbiologist Lynn Margulis, who interpreted endosymbiosis – *i.e.*, the ingestion/fusion/internalization of one organism by another – as a driver in the evolution of living organisms (Margulis & Sagan, 1986). This hypothesis has since been reinforced by the discovery of the viral origin of glycoproteins such as syncytins, which are necessary for placentation

(Dupressoir & Heidmann, 2011). It appears, indeed, that mammals owe their existence to their ancestors' infection by viruses.

Since that time, the notions of microbiome (the whole genome of the microbial populations in a given environment) and microbiota (the complex ecosystem of these microorganisms) have flourished, marking out the deeply relational and systemic nature of the modes of existence of living entities (Douglas, 2018). As crucial players in ecosystems, they also appear to be essential for the development and maintenance of macro-organisms. The latter are no longer considered as discrete and individual entities but as multispecific and symbiotic complexes: endlessly renewed assemblages of more or less sustained interactions and associations amongst several species, in which microbes play various roles at different levels, for example genetic, physiological, immunological or developmental (Gilbert, Sapp & Tauber, 2012). Biologists have proposed the term holobiont (from the Greek holo: "whole" or "all" and bios: "life") to name these chimeric entities (Gilbert & Tauber, 2016; Skillings, 2016). This redefinition of ecosystems, organisms and what constitutes them has in fact been accompanied by a reconsideration of ecologies, states of health, and the etiologies of several pathologies, which are now examined from a perspective of ecological balance or disturbance, though without elucidating the mechanisms at work (Blaser, 2014; Lorimer 2020).

These changes were quickly embraced by some social science researchers who therefore called for the need for interdisciplinary approaches to understand how this microbial "irruption" required a rethinking of all the classic questions of anthropology (Benezra, DeStefano & Gordon, 2012) and the notion of the 'self' (Rees, Bosch & Douglas, 2018), even going so far as the proposition to rename *Homo sapiens* as *Homo microbis* (Helmreich, 2015). In a recent review of literature in ethnobiology, Andrew Flachs and Joseph D. Orkin pointed out that "Kitchens and gardens influence microbial ecology in dramatic and complex ways because humans manage agri-food systems: humans domesticate species, change habitats, and process foods in ways that have distinctive effects on microbial communities in our homes, our foods, and our guts." (Flachs & Orkin, 2019, p. 35, or Greenhough *et al.*, 2018).

It must be pointed out that this "microbial turn" mainly concerns the countries of the North, which have seen a conspicuous renaissance in fermentation practices and the interest taken in them by the social sciences, new metagenomics technologies allowing the production of a profusion of unpublished data, and the human and social sciences redefining their agenda accordingly. This is a limitation that has not gone unnoticed by Paxson & Helmreich, particularly when they point out that the microbial history they are describing, and the changes it has undergone, must be seen above all in the context of the ideological and institutional history of the United States (2017), or by Jamie Lorimer, who has associated the "probiotic turn" with what he calls the "WEIRD" (Western, Educated, Industrialized, Rich and Democratic) world (Lorimer, 2020 p. 1). But when contextualized in this way, are these elements enough to say we are truly witnessing a turn?

Putting the scope of the "microbial turn" into perspective

There is indeed a risk in asserting too quickly that there has been a "turn" without at the same time documenting in detail the ambivalence of microbes and the practices previous to or associated with them. One problematic aspect of the concept of the "microbial turn" and the notion of "post-Pasteurian cultures," aside from the fact that they may appear totalizing, is that they also introduce the notion of a tipping point between two periods. Generally speaking, then, there would be a "before," characterized by a perception of microbes as heralding a threat that is essentially negative (the pathogenic microbe) and discrete (or unitary, excluding relationships), and an "after," characterized by a positive (microbes that are beneficial to human, animal and plant health; essential role of microbes in various ecosystems) and ecological vision (studies of intra- and inter-species relationships, and relationships with the environment), where microbes have a promising aspect.

Paradoxically, it was a similar movement, designated by other highly debatable (and debated) expressions, that characterized the "before" supposedly followed by this "microbial turn"; it was called the "bacteriological revolution" or the "microbial revolution." This revolution would have led to the discovery of these microscopic beings whose pathogenic power could have been tamed by the genius of a few men. Historian of science Ilana Löwy has nevertheless asserted, paraphrasing historian of science Steven Shapin (Shapin, 1996) in a text devoted to microbes and humans, that "the microbial revolution did not take place" (Löwy, 2015). Rather than seeing in the historical moment described by this expression a uniform and totalizing movement (brought about by important personages), she has shown that in fact this should be seen as a series of modifications and displacements applied to a diversity of separate practices, based in part on previous knowledge, know-how and recommendations. But the "microbial turn" is not a "bacteriological revolution." What's interesting about the notion is that it indicates the centrality not so much of a discipline, even a discipline essentially centered on the control of infectious diseases, but of microbes themselves, and thereby indicates a movement with a broader multidisciplinary impact across practices and knowledge related to microbes, and a departure from the tutelage of infectious microbiology.

In her work devoted to the invention of the "microbial body," Funke Iyabo Sangodeyi sought in particular to situate the current microbial moment within the longer history of minor practices: from oral microbiology to the broader movements criticizing chemical hygiene products. This involves two key issues: on the one hand, preventing a return to the relative invisibilization of practices that were previously minor and/or underestimated, yet without which the renaissance in human/microbe relations would never have occurred; and on the other, giving critical attention to the contemporary microbial craze and understand the reasons for it. How and why has certain knowledge had more of an echo, or produced more impact than others in the sciences and in society as a whole? What are the forces that gave rise to the current configurations? What opportunities, what dangers do they indicate? It is not our intention to fully answer these questions here. We would be unable to do so. We must simply leave them open, so that they remain as focal points to be monitored by others specifically concerned with such questions.

Relativizing the novelty: microbes and ecologies before the 21st century

It is not insignificant that accounts of the discovery/invention of microbes in the 19th century are frequently associated with this so-called "bacteriological revolution."[6] Bruno Latour taught us to reconsider that revolution, not from the perspective of important personages, but rather from that of the microbes themselves, seen as socio-technical objects linking together a whole network of gradually-assembled objects and actors, and linking pure laboratory cultures to the larger world of European, American and colonial societies (Latour, 1984). The practices and methods of producing fermented products and the medical conception of disease have all been progressively transformed by bacteriological practices. In regard to fermentation, the selection and optimization of bacterial strains or "blends" of strains has led in industrialized contexts to the standardization and homogenization of the microbes used, while at the same time intending to avoid certain strains deleterious both to the production process and to consumer safety. As for diseases,

> The move toward bacteriological theories [...] marks an important if incomplete shift [...]. Initially, those who embraced germ theory melded the new ideas with their long-standing environmental beliefs; ecological and modern concepts of the body coexisted openly and easily for some time. Nineteenth-century physicians were likely to see germs everywhere, and as capable of penetrating the body in multiple ways. However, the increasing dominance of bacteriology encouraged doctors to narrow their definitions of health and limit their focus to the specific pathogenic agents that were revealed under the microscope (Nash, 2006, p. 12).

Koch's approach to bacteriology sanctioned the production of cultures deemed to be pure, representing agents of disease. Thus, microbiological knowledge has long been based on the possibility of isolating and cultivating microbes in the laboratory: a long learning process, requiring specific know-how, ranging from the preparation and standardization of growth media to the possibility of sharing, preserving and storing microorganisms. By purifying and simplifying media, microbiology laboratories have made possible the systematization of taxonomies and the distribution of the microbial world into distinct species (Gradmann, 2009; Grote, 2018). An article in this issue by Mathilde Gallay-Keller describes in detail the emergence of the first collection of microbes from the Pasteur Institute, a collection based on a distinction between pathogenic microbes and industrial microbes, and which excludes the latter (see also Strasser, 2019). She thus describes the multiple functions these collections have been able to fulfill, notably in the production and maintenance of a "Pasteurian" culture demonstrating the new "control" it promised and at the same time establishing the legitimacy of these actors and proposing a new microbial order. Microbes thus gradually became the standard for understanding and controlling epidemics (Lock & Nguyen, 2010), and infectious diseases came to be seen as solely the product of the action of microbial pathogens.

Microbiology, particularly in colonial environments, has moreover played a central role in the development of the notion of a medical practice underpinned by a universal scientific paradigm (Moulin, 1996). The notion was strengthened when it became possible to do without a detailed understanding of environments, territories, climates, biosocial specificities and bodies, and simply examine their impact on microbial

circulation alone. In other words, the invention of microbes by bacteriology provided a powerful technoscientific means of controlling and stabilizing the consequences of microbial exchanges generated by increasing urbanization, colonization and commercial globalization. It thus cultivated the idea of a biological equivalence of bodies (a universal biology), and faith in the possibility of the eradication of pathogenic microbes by the invention of biomedical technologies such as vaccines, and antibiotics after World War II. At the same time, critical analyses of the dominant narratives of epidemics (Larson *et al.*, 2005; Wald, 2008) and of immunity (Martin, 1995) have highlighted the constructed, partial and problematic nature of these narratives of eradication, and of the characterization of microbes as enemies of public health.

A more recent anthropology, using terms such as biosecurity and preparation (Collier, Lakoff & Rabinow, 2005; Lakoff & Collier, 2008) to describe a new risk rationality in the management of living organisms, has sought in turn to analyze the recent specifics of the modes of global epidemic management and the invention of surveillance, tracing, and related modeling systems (Caduff, 2015; see also the essay review in this issue by Farmer, 2020; and, for a relativization of the alleged novelty of these systems, see in particular Fortané & Keck, 2015). This literature, which reflects the centrality of the notions of "emergence," "animal reservoirs," or even "species barriers," confirms the persistence of a perspective centered on microbes (and not on the broader ecologies that their potential pathogenicity implies) within these risk rationalities. The key point that emerges here is that microbes continue to flout the systems put in place to try to control them. Indeed, it was known and documented well before the early 21st century that microbes are ambivalent, and that more ecological perspectives are necessary to understand them.

This narrative of microbial enemies consisting of various distinct species, in which our knowledge and specific techniques have made it possible to act "as if" it were possible to detach them from their specific environments and work toward the development of a universal biology, can thus be told in a different way. There is a considerable literature to the effect that the success of bacteriology, even when considered in terms of the networks to which it owes its strength and existence (Latour, 1984), has not been immediate or homogeneous. Its "application" to clinical work was by no means obvious (Mendelsohn, 1996), and the production of therapeutic agents resulting from bacteriological research was strewn with failures and trial and error (Worboys, 1992), just as the specific description of pathogens and the development of screening tests were strewn with controversy (Fleck, 2006). Frédéric Vagneron's article in this issue takes stock of these questions and shows how at the end of the 19th century, in the case of the "Russian" influenza pandemic (1889-1890), efforts to attribute a specific agent to the pathology have quite simply failed. Lively debates involving various different medical specializations and questioning both the identity and the variability of the disease and the legitimacy of these specializations, questioned even the very existence of the disease. This was not the result of a lack of knowledge, but a sign of the existence of different conceptions of disease, rejecting its reduction to a pathogenic agent and considering a multiplicity of causes – association of microbes, the medical specificities of each subject, broader environments – that may be able to explain it. Marine de Guglielmo, discussing the notion of "post-Pasteurian cultures" in her contribution to this issue, returns to the figure of Pasteur and shows how his work was far from able to confirm the idea of an essentially hygienic and antimicrobial notion of science. On the contrary, apart from their relevance to industrial processes, Pasteur and some of these

collaborators developed a strong conception of the broader usefulness of microbes within biological worlds, developing a concept of their use in human medicine that the author describes without hesitation as "probiotic." She also pays particular attention to the variety of objects and micro-organic beings invented or addressed by Pasteur, leading us to consider in a more complex manner this multiplicity of beings and objects that we sweep together today into the category of microbes. The stability of bacterial species, and the control and understanding of variation in the microbial world has also remained an open question (Mendelsohn, 1996). The historian Warwick Anderson in turn has shown that an "ecological vision," characterized by a consideration of the relationships between disease, environment, and evolutionary processes, remained a persistent presence in the work of scientists such as Theobald Smith, Francis MacFarlane Burnett, René Dubos and Frank Fenner. This ecological vision remained in the minority until the early 1980s, when it was applied to explain disease emergence and antibiotic resistance (Anderson, 2004). At a time when antibiotic resistance, and more generally the impoverishment of certain ecosystems began to emerge as a major problem, ecological and evolutionary mechanisms able to provide an explanation thus saw a resurgence of interest.

Finally, some anthropologists describe the ways in which, on the fringes of a global health system with a universalist aim, very concrete relationships to microbes are negotiated within specific local environments, which are much richer and more varied than those linked to a biomedical science of control and command (Kelly & Beisel, 2011; Nading, 2014 – and for a critique of global health strategies, see Farmer, 2020 and the essay review in this issue). Entering into dialogue with and explicitly relying upon more-than-human ethnographies, multispecies ethnographies (Kirksey, 2014; Kirksey, 2019; Kirksey & Helmreich 2010; Helmreich, 2009), or on the notion of companion species (Haraway 2018) these studies offer us many perspectives, giving us an idea - both in biological and political terms – of how humans and non-humans reciprocally shape one another, and the variety of forms of interaction this implies.

In all these cases, from the laboratory to the fields of global health, what has made and still makes impossible the surveillance and control of microbes is the persistent relevance of broader environments: the reciprocal shaping of environments, humans and microbes, and the interweaving of relationships inextricably combining social and biological dimensions - or, in the words of historian Linda Nash, inescapable ecologies (Nash, 2014).

If we move away from the exclusively biomedical perspective, as we are invited to do by the notion of the "microbial turn," the construction and persistence of traditions of microbial ecologies in the fields of marine and soil microbiology become all the more visible (O'Malley, 2014; Grote, 2018; Pessis, 2020). It was in these fields of study that questions relating to the relevance of species categorizations and the plurality of modes of relationships with and between microorganisms were widely explored throughout the 20th century.

All of these elements, which we acknowledge are hardly exhaustive, demonstrate the need to avoid referring to a "microbial turn" without nuance. Though there has been a "turn" in certain practices, it must be seen more as a relative reduction in the blindness to or partial obliteration of certain types of knowledge that were difficult to reconcile with perspectives of globalization, standardization and eradication.

Relativizing the promise: the infrastructure of practices and knowledge

As should be clear, this discussion on the relevance of the notion of the "microbial turn" is not limited to a more or less scholarly exegesis of a corpus of texts and theoretical ambitions. To talk of a "turn" or a "revolution" is a substantial (scientific and political) gesture. As we have seen, it not only describes, it also prescribes. It both illuminates and obscures. It includes just as much as it excludes. And at the same time as it refers to a present condition, it opens to assured futures, and inevitably commits to an economy of promise (Audetat, 2015). Thus, Ilana Löwy has pointed out, in regard to the "microbial revolution," that "at the beginning of the 20th century, the perception of (...) a change was based much more on the hopes raised by the development of microbiology than on its actual achievements." (Löwy, 2015, p. 238).

Couldn't the same be said about the "microbial turn"? After all, at the same time as these authors are describing this "turn," they are also expressing their *hope* for its advent, or, at least, rekindling certain hopes. Heather Paxson and Stefan Helmreich mention this explicitly. As they write,

> Model ecologies are contemporary tools that scientists and their interlocutors (including us, as authors) use to describe desires for exemplary ways of studying human entanglements with nonhuman agencies (Paxson & Helmreich, 2014, p. 185).[7]

And at the same time, they say, "such ecosystems offer to a variety of scientists and laypeople new hopes of a not yet tamed or fully known nature, a future nature." (*ibid.* p. 168). A "nature" which, as described, could also come to prescribe what "human ecological relations with living organisms *could, should, or might be.*" (*ibid.*). Indeed, theorist Melinda Cooper had already been calling for us to be vigilant about this, regarding the way that, as in the work of Lynn Margulis and James Lovelock, the development of a powerful microbial theory was able to help minimize the impacts of industrial pollution, which nevertheless cannot "stop the evolution *of life itself*." (Cooper, 2008, p. 36). Current work on microbiota and its insistence on the beneficial aspects of vaginal birth and breastfeeding may also result in a naturalization of mothering practices, with all the deleterious consequences this may have when coupled with injunctions in particular. From another angle, current research on a supposed ancestral microbiota has also contributed to a renewed racialization of human communities (Benezra, 2020).

A pathbreaking article by science historian Hannah Landecker on antimicrobial resistance offers a striking example of how knowledge and the promises associated with it can radically transform not only societies, but also biologies. The author describes how the invention, industrial production, and massive use of antibiotics and the knowledge associated with them made it possible in particular to act "as if" the environments in which microbes evolve could be neglected. Antibiotics thus facilitated the production of many large-scale developments:

> more health, more meat, more fruit, more surgery, less death, more fertility, in everything from in vitro embryos cultured in anti- biotics to fish farming (Landecker, 2016, p. 20).

And thereby, they profoundly and irreversibly transformed the very biology of microbes. By analyzing clinical and soil samples, stored over several historical periods,

we can deduce a "biology of history": the physical traces left by human history on bacterial life (Landecker, 2016).

These collections, which are a recurring element in this issue (Brives & Froissart, Gallay-Keller, Tancoigne, Demeulenaere & Lagrola), testify to the vital importance of these institutions in the production of knowledge and the maintenance of practices associated with microbial worlds. They crystallize a particular state of knowledge as well as “microgeohistories”: the stories of the collective and situated transformations of practices, territories and biologies (Brives, 2021).

There is however always the obvious risk of obliterating the conditions and logics that underpinned their original production when they are brought out and used to mitigate the consequences of modern knowledge and practices. As Bowker and Star have shown about classifications considering as infrastructures of knowledge, there are epistemological, political and ethical consequences to the approach of systematic classification, sorting, discrimination, and ordering (Bowker & Star, 1999). Insofar as this approach involves the sorting of real elements and serves as a guide for action, microbial classifications and the knowledge produced from them and the ontologies underpinning them have real consequences; by including and excluding, they may create new possibilities and open up new fields of research, but especially when linked to a project specific to late industrialization, they can also generate blind spots and lead to a rigidification of entire domains of knowledge, along with uniformization and standardization in order to respond to injunctions of mass production.

It is within this particular environment, located within regulatory, economic and political structures which constrain them and which they can help transform, that efforts are being made to develop alternatives, some of which are documented in this issue (Demeulenaere & Lagrola, Brives & Froissart). Exploring these alternatives, these ways of responding to the consequences of the application of previous states of microbiological knowledge, then forces us to think twice about that environment, to avoid the risk of repeating the same misguidance and errors and coming to the same dead ends.

The contributions with regard to fermentation quite particularly call our attention to this point. A whole movement of reinventing practices and care for microbes has arisen in opposition to the substantial standardization of agricultural modernization, and has raised the alarm on the loss of microbial biodiversity (see below). These tensions between industrialized and standardized production practices on the one hand and more idiosyncratic, local and artisanal practices on the other are intensified precisely by the ambivalence of the relations between humans and microbes: the need to allow the flora necessary for the transformation of the substances to flourish, whilst also seeking to guarantee consumer safety. Élise Demeulenaere and Mathilde Lagrola return in this issue to this tension: in order to address the impoverishment and simplification of microbial flora in milk in the context of the production of raw milk cheeses due to technical and regulatory changes concerning the quality of milk in particular, the authors analyze how a group of researchers and practitioners are reinventing "managed microbial ecology" practices and indicators competing with existing standards (Demeulenaere & Lagrola, 2021).

But even when producers seek to break with production methods based on standardization and therefore reinvent their practices based on an exploration of the multiple relationships that can be maintained between humans, microbes and their

environments, based on efforts to update and reinvent what may often be centuries old knowledge, it is difficult for fermentation practices to escape the regulatory frameworks and economic models in place.

In this issue, Charlotte Brives and Rémy Froissart examine the impact of infrastructure on the development of alternative practices in relation to phage therapy, *i.e,* the use of bacteriophage viruses to treat antibiotic-resistant bacterial infections. They show in particular how the very possibility of a therapy truly taking into account the evolutionary and involutionary capacities of living beings implies a collective reimagination of the dominant models of drug development and the ontological status assigned to microorganisms, at the risk of otherwise reproducing the same errors as have occurred with antibiotics. This is the argument that can also be drawn from reading Élise Tancoigne's contribution, which, in describing three systems of microbial selection for the production of raw milk cheese - the modernist, environmental and regional - shows how the last two ultimately form part of the lineage of the modernist regime, and struggle to distinguish themselves from it.

Conclusion

This issue of the *Revue d'anthropologie des connaissances* thus provides a snapshot, though incomplete, of the state of current research in the social sciences of microbes. Work on the subject of fermentation appears to have an dominant position, but many current issues regarding microbes are not addressed. This under-representation can be explained by the temporalities and specificities of ethnographic research, which require a long immersion and understanding and appropriation of the practices studied. Research on the subject now continues, and has been made visible by programmatic articles (Greenhough et al., 2020; Benezra, DeStefano & Gordon, 2012), as well as by various conferences and study days.[8] Another difficulty faced by these studies lies precisely in their highly interdisciplinary nature: an understanding of social and biological dimensions requires the sharing of onto-epistemological methods and approaches specific to each discipline, often requiring sustained efforts of translation, articulation and diplomacy (Stengers, 2006).

Metagenomics and the profusion of data now available have indeed contributed to the development of interdisciplinary studies in which the social sciences are strongly involved. This is the case, for example, with the "Heirloom Microbes" project on dairy practices, combining archeology, microbiology and anthropology.[9] This is also the case with research on human microbiota, which has been leading to a reconfiguration of dietary and care practices, which had been shown to have led to an unprecedented alteration of flora, and the resulting remedial efforts (Zimmer, 2019). Likewise, the development of molecular phylogeny appears to offer a source of new and additional data for the social sciences: this history contained in microbes now makes it possible to reanalyze epidemics and offer new narratives (Lachenal, 2011; Pépin, 2019).

For complementary approaches, however, we would like to mention two collective works to be published in 2021: *The Arts of the Microbial World,* on fermentation in Japan in the 20th century (Lee, 2021), as well as *With Microbes*, which compiles twelve ethnographies of the relations between humans and microbes (Brives, Rest & Sariola, 2021). This special issue does not therefore claim to be exhaustive, especially in view of

previous developments. The social sciences on microbes are set to embrace this diverse variety of practices more widely in the coming years.

The state of the literature on microbes and the articles presented in this issue all address a variety of practices, different microorganisms, and the contextual nature both of interactions between living organisms and the production of knowledge in different historical periods, requiring thus to recall the importance of the socio-environmental and biological environments in which this knowledge has been produced and applied. At the same time, there is a tendency for scientific practices to claim to be able to act "as if" the environments where this knowledge is applied were secondary; the consequence, as has been pointed out, has been ecosystem impoverishment and microbial resistance phenomena.

Alternatives, however, have been obliged to grow in a world of knowledge, regulation, economic infrastructures and ecologies containing tendencies that developed over the 20th century, thus drastically constraining the field of possibilities. These alternatives must take particular care to avoid symmetrically reifying categories known to the life sciences and human sciences to be of a constructed nature: both the category of "human" and the category of "microbe" contain immense diversity and varied modes of existence, which require special attention. Each time and in each situation, there is a risk of repeating the approaches the actors wish and claim to escape, and of thereby doing violence to the various beings involved.

Thus, there will be no "microbial turn" or radical renewal of this ever greater number of relationships, that is able to take into account the ecologies, the indeterminate nature of biologies, and the potential of joint transformations of environments, microbes and human beings, except when serious consideration is given to the environments where this knowledge is produced and in which it circulates and is applied. This also brings up the fact that there is no such thing as apolitical scientific inquiry (Collectifs d'enquêtes politiques, 2016) and that if the politics of scientific inquiry are neglected, we may fall back in spite of ourselves into approaches that contribute to the harmful alteration of human and more-than-human ecologies.

This work received funding from the Idex at the University of Strasbourg, from the Agence Nationale de la Recherche (ANR-18-CE36-0001), and from the Nouvelle-Aquitaine Region (2018-1R40218).
We would like to thank the members of the editorial board of the Revue d'Anthropologie des Connaissances, and more particularly Élise Demeulenaere and Dominique Vinck for their support. We would also like to thank Celia Miralles and Frédéric Vagneron, from whom one of the authors learned a great deal about epidemics and their environments.

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NOTES

1. Though these expressions do not strictly coincide - further below we will address some of their distinctive features - we will primarily be discussing the notion of the microbial turn.

2. The criterion of invisibility to the naked eye holds only very superficially, and is based on individualization and a single-cell approach to microorganisms: in fact, during their life cycle, many exist in communities that can act as a single entity, governed by a complex division of labor. An example of this might be biofilm, which can cover a very large area, like a lake, and may therefore be observable without the use of any instrumentation. Viruses are the subject of intense debates as to whether or not they are living organisms, debates which are informative as to how the way we think about life and viruses has changed according to the times, the disciplines approaching them, or even the questions being asked about them (Kostyrka, 2018). See also the special issue of the journal *Studies in History and Philosophy of Biological and Biomedical Sciences* edited by Pradeu, Kostyrka and Dupré: "understanding viruses, philosophical investigations." The contributions of Demeulenaere and Lagrola, as well as that of de Guglielmo - the first based on an analysis of fermentation practices in the production of milk cheese and the second based on a semantic analysis of Pasteur's corpus – discuss the overinclusive nature of the category of microbes.

3. If we look at bacteria, for instance, they can be classified according to the sequence of a particular gene (such as 16S RNA), based on a morphological feature (cell wall), or on a metabolic

function, to name only a few criteria. Viruses, on the other hand, may be classified based on the shape of their capsid, the nature of their nucleic acids (RNA, DNA, single- or double-stranded, for example), their host range, etc.

4. Our comparative review of works applying the notion of the microbial turn is not exhaustive – it sometimes overlaps with the notions of a post-Pasteurian or probiotic turn. We simply wish to point out that this spectrum of notions was quickly taken up in the literature.

5. For example, metagenomics has made it possible to identify significant genetic and ecological variation among organisms that are nevertheless phenotypically identical and thoroughly studied in laboratories, such as the bacterium *Escherichia coli*. For an overview of the history of the different characterizations of *Escherichia coli* and its multiple and varied existences, see Will & Erickson, 2021.

6. Which Ilana Löwy, in particular, prefers by contrast to refer to as the "microbial revolution."

7. The authors prefer the notion of "model ecologies" to that of "model ecosystems," since the term ecology also refers to the theoretical description of organic relationships.

8. See for example the study day entitled "Nos vies microbiennes, un forum contre l'éradication" [Our microbial lives, a forum against eradication] organized by Victoria Lee on May 27, 2021 (https://www.paris-iea.fr/fr/evenements/nos-vies-microbiennes-un-forum-contre-l-eradication or the study day "Microbes et microbiologie, vers de nouveaux récits?" [Microbes and microbiology, towards new narratives?] organized by Matheus Alvares Duarte Da Silva and Mathilde Gallay-Keller on June 15 and 16, 2021.

9. https://www.shh.mpg.de/349696/heirloom-microbes

ABSTRACTS

This issue of the *Revue d'Anthropologie des Connaissances* questions and puts into perspective the notion of a "microbial turn," which has appeared recently in the microbial social sciences field and more broadly in multispecies studies. After reiterating their definition and the definition of some associated notions, this introduction discusses them by contextualizing them within certain neglected traditions of the natural sciences and of a broader literature in the social sciences. This allows the authors to reengage on the one hand with a variety of narratives and approaches regarding human/microbe relationships that preceded this so-called turn, and on the other hand to highlight focal points of attention in regard to the promises attached to them. This effort to relativize the novelty and the promises of this "turn" is not intended to disqualify this notion, but to relocate it within infrastructures of wider practices and knowledge, in order to propose that it be taken up whilst giving careful attention to the conditions and political consequences of this turn.

Ce numéro de la *Revue d'Anthropologie des Connaissances* interroge et met en perspective la notion, récemment apparue dans le champ des sciences sociales des microbes et plus largement dans les études multispécifiques, de « tournant microbien ». Après en avoir rappelé la définition, ainsi que celles de notions qui lui sont associées, cette introduction les discute en les resituant au sein de traditions négligées des sciences naturelles et d'une plus vaste littérature de sciences sociales. Ceci permet d'une part de remobiliser une variété de récits et d'approches des relations humains/microbes qui précède ce prétendu tournant, d'autre part de souligner des points de vigilance quant aux promesses qui l'accompagnent. Relativiser la nouveauté et les promesses de

ce « tournant » ne vise pas à disqualifier cette notion, mais à la resituer au sein d'infrastructures de pratiques et de savoirs plus larges, afin d'en proposer une reprise attentive aux conditions et conséquences politiques de ce tournant.

Este número de la *Revue d'Anthropologie des Connaissances* cuestiona y pone en perspectiva la noción de «giro microbiano», surgida recientemente en el ámbito de las ciencias sociales de los microbios y, a nivel más amplio, en los estudios multiespecíficos. Tras recordar su definición y las nociones asociadas, esta introducción las aborda en el contexto de tradiciones olvidadas en las ciencias naturales y de una literatura más amplia de las ciencias sociales. Esto permite, por un lado, movilizar de nuevo una variedad de narrativas y enfoques de las relaciones entre los seres humanos y los microbios que preceden a este llamado «giro» y, por otro lado, subrayar puntos de vigilancia respecto a las promesas que lo acompañan. Relativizar la novedad y las promesas de este «giro» no pretende descalificar este concepto, sino resituarlo dentro de infraestructuras más amplias de prácticas y conocimientos, para proponer una continuación atenta a las condiciones y consecuencias políticas de este giro.

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Palabras claves: giro microbiano, revolución bacteriológica, fermentación, ecología microbiana, infraestructura de conocimientos, medicina
Keywords: microbial turn, bacteriological revolution, fermentation, microbe ecology, infrastructures of knowledge, medecine
Mots-clés: tournant microbien, révolution bactériologique, fermentation, écologie des microbes, infrastructure de connaissances, médecine

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