Humans, Microbes and Soils

A Multi-sited Ethnography

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Table of Contents

List of Figures

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Declaration

I declare that the thesis is my own work and has not been submitted for a degree at another university.

I have drawn upon reflections from this project for the following article:

Zanzu, S. (2019) Le dimensioni sociali della vita del suolo, *A rivista anarchica*, 432(2):52

Abstract

This thesis is about the formation, circulation and transformation of a specific knowledge that emerges in the scientific laboratory and then travels outside its boundaries. It explores the constitution of the soil microbiome field across multiple kinds of practices, expertise and sets of interests in the UK. While the microbial world is increasingly considered worthy of sociological attention, to date the microbial communities of soil and the humans who co-create the knowledge about them, have received little consideration. This thesis locates its contribution to this under-researched area of study, arguing for a sociological recognition of these invisible and neglected entities as lives that count.

Undertaking a multi-sited ethnography, I follow soil microbiome knowledge as it travels across agricultural fields, scientific practices and policy deliberations. In a recursive shift of positions and sites, I examine the interrelations, ambivalences and complexities of scientific, growing and policy approaches to soil microbial communities. I explore the future-oriented technoscientific attitude of exploitation pervading this field, entangled with farming and sustainability agendas, and the tortuous circulation of this knowledge as it traverses convoluted attempts at policy translations while facing public inattention.

Looking for more speculative possibilities beyond an instrumental view of soil and microscopic life, I argue that the microbial communities of soil also emerge as ineffable entities yet able to assert themselves as embodied and transformative. I consider the possibility of repositioning the human within the soil field where novel microbial entanglements can initiate a process of 'becoming' in those who let themselves be moved by microbes. These relationships are continuously reinvented in their potential to alter the scientific questions asked and the way humans and microbes experience and affect the world.

Chapter 1. Introduction

Emerging microbial communities

What is a microscope doing at a food growing cooperative? How does this primarily scientific instrument find its way into agricultural fields? This thesis addresses how the microbiology of soil has come to matter beyond the scientific sphere, to reach growing projects and policy debates. It examines in particular the emergence of the soil microbial communities as an object of enquiry in the UK context. It looks at the different practices and authoritative forms of knowledge-making that co-produce the soil microbiome as a scientific and social entity. It considers how different kinds of expertise shape the definitions of these communities and how soil microbiome research circulates and is translated across knowledge fields. In exploring practices that constitute and affirm microbial communities as significant, the thesis also addresses the possibilities for novel human/microbes relationships.

Figure 1: Microscope at a UK food growing cooperative

Microbiomes are 'complex communities of microbes associated with humans, animals, plants and other environments such as soils and oceans' (Microbiology Society, 2020a). Ninety percent of microbes, including bacteria, algae and viruses live under the earth surface (Frank, et al., 2013). The soil microbiome is the collection of microorganisms that live in the soil. Recent developments in genetic technologies

allow for an improved understanding of widely unknown soil microbial communities (Fierer, 2017). One gram of soil can contain between 10,000 and 50,000 species of microbes (Chaparro, et al., 2012). The soil microbiome is considered responsible for healthy, disease-resistant and productive plants. Microorganisms form highly dynamic relationships with plants. They send chemical signals to which plants respond with exudates from the roots. These root exudates influence the composition and functionality of the microbial communities. While until recently the interaction between plants and microbes has been overlooked or simplified, current advances in research allow for a move away from characterising single species interactions, to focus instead on the functional influence of the whole community. This is because in the interaction with plants and the resulting crop health and yield, it is the large community, rather than specific microbes, that matters (Chaparro, et al., 2012).

In the current recognition of the finitude of resources and the depletion of soils, the management of microbial communities is seen as the answer to restoring soil health and reducing fertiliser use (Chaparro, et al., 2012). Because of its ability to influence crop and therefore food production, soil microbial communities emerge as critical across UK food policy debates concerning the future of agriculture in an increasing environmentally damaged soil. The soil microbiome is therefore interwoven with the need for the restoration of depleted soils and the employment of farming methods that can ensure a more sustainable food production. In the context of a growing sense of urgency in addressing issues around soil degradation and its impact on food production and environmental damage, food policy experts warn about the effect of large scale agriculture that relies on pesticides and fertilisers on soil erosion, with a decline in food productivity (Lang, Barling and Caraher, 2009).

This awareness is reflected in an increased governmental attention to the state of UK soils. The policy paper '25 Year Environment Plan' that outlines the UK environmental strategy in diverse areas including air, water and biodiversity, recognises the necessity of restoring soil (Defra, 2018). A number of recent policy reports and programmes aim at mapping the main issues facing soil, such as the 'Soil Health' report (House of Commons Environmental Audit Committee, 2016). The biology of

the soil is recognised as the important component so far neglected in the understanding of soil. In one of these instances, the UK Parliament briefing 'Sustaining the Soil Microbiome' specifically addresses the soil microbiome as the element that 'underpins many of the ecosystem services that benefit humans' (POST, 2019:1). The report underlines the benefits of the soil microbiome for plant health, soil structure, pollutant decontamination and as an indicator of soil health. Because of the pressure posed to these communities by agricultural pesticide and fertiliser use, urbanisation and climate change, the report calls for the need of 'restoring the soil microbiome' (2019:4). The promotion of these governmental and policy initiatives around the importance of a biologically healthy soil makes policy one of the forms of knowledge-making involved in the constitution of the soil microbiome.

Because farming practices are recognised as having a significant influence on the soil microbiome, the concern around the biology of soil has reached the UK agricultural sector, where farming organisations and bodies are turning their attention to methods aimed at increasing biological activity. In one of these instances, the Agriculture and Horticulture Development Board and the British Beet Research Organisation launched the 'Soil Biology and Soil Health Partnership' aimed at addressing the inadequacy of knowledge and understanding of soil biology to assist UK farmers and growers in improving agricultural productivity (AHDB, 2020a). The programme specifically mentions the soil microbiome with reference to its objective 'to benchmark the composition of the soil microbiome to be able to analyse changes in the microbial community over the life of the subsequent crop' (AHDB, 2020b:7). There is a sense that despite a recent increase in attention to the biology of soil, this element is still far from being understood. The programme aims at improving and applying this knowledge practically in agriculture.

Given the recognition of microbial life as important in the understanding of soil, this thesis explores the emergence of soil microbiome knowledge as it traverses the scientific, policy and agricultural domains. It interrogates in particular the interwoven ways in which the knowledge around the soil microbial communities is constituted across fields of expertise. Looking at the circulation of this knowledge can elucidate the interconnected nature of an object of study that cannot be defined in purely

scientific terms but needs to be understood in the context of related social spheres and practices. By examining the claims, questions and definitions proposed in soil microbiome research, in the following chapters I witness its departure from the site where it originates, the laboratory, and the ways in which it travels and transforms itself across growing and policy fields. To 'know' the soil microbiome is to follow the ways this knowledge circulates, shapes and is changed in turn by the communities of practices it touches.

How is the soil microbiome constituted across knowledge spaces?

In order to explore the interconnected dynamics at play in the formation of soil microbiome knowledge, my research considers the broad aims and issues addressed in the field and the realities produced as a result. How does the soil microbiome come to matter as a scientific object? How do microbes become seen as technologies? The awareness that soil microbial communities are constituted beyond the laboratory prompts further research questions around the intersection of multiple forms of knowledge-making. How do different practices and expertise co-produce the soil microbiome as an entity worthy of attention? How does the soil microbiome circulate across fields, traverse knowledge spaces and affect the sites it enters? How is this knowledge transformed by the different practices involved in its constitution?

Despite the many unknowns in regard to the composition and functionality of the soil microbial communities and their complex interaction with plants, the soil microbiome field proposes the assumption that further studies in the area will enable to translate results into practical applications for plant growth and soil fertility. As I discuss further in chapter four, there is a sense that a better understanding of the soil microbiome will allow for its manipulation, by encouraging for instance the use of microbial products or by engineering new symbioses between plants and specific microbiomes. These interventions, oriented towards the future, are considered able to reduce the use of chemicals in the soil, thus allowing a transition towards a more sustainable agriculture.

One of the key arguments of this thesis is that the solution-oriented narratives present in the soil microbiome field promote a technofix approach to soil, food and environmental issues. They also contain an anthropocentric view of microbial life as there to be harnessed, manipulated and arranged for human use. The thesis contends instead that soil microbes matter intrinsically and beyond human benefits. An attention to the microbial communities of soil opens the possibility to seeing humans as members, rather than managers, of the soil community, the community of organisms, including plants and microbes, that live on the earth. The thesis also argues that in order to relate to an invisible and neglected life it is not necessary to resort to abstract conceptualisations. On the contrary, it is the difficulty of connecting with microbes that requires forms of knowing that rely on the senses, an element I explore in chapter five. While microbes may not be directly seen, their activity can be perceived by touching and breathing soil.

Furthermore, the thesis argues that engaging with specific forms of life that are neglected and challenging to relate to, such as soil microbial communities, can offer a contribution to a sociological understanding of the relationship between humans and microbes. It can tell us more about other 'others' not high in the categories of difference that sociology holds dear. But what might a sociology of soil microbes look like? Asking this question may lead to new ways to reconsider human-centred sociologies, in favour of disciplinary endeavours that attend to microbial life in its specific invisibility and disregard. It allows for an exploration of relationships beyond anthropocentric attitudes often entailing the exploitation and manipulation of other living beings.

More broadly and speculatively, taking microbial life seriously means examining novel possibilities of thinking about the relationship between humans and microbes in their transformative potentials. The different kinds of relationships I propose throughout the thesis and especially in chapter six, entail the assertion of the microbial liveliness of soil and an engagement with microbes that implies awareness, attention and relevance. These are human/microbe exchanges not intimidated by invisibility and scale, but that on the contrary derive their meaning from the imaginative ways required to connect with an unseen yet valuable life. These

decentred relations can also involve an awareness of microbes as human ancestors and may bring a repositioning of the human within the environment that takes into account visible and invisible life forms. Transformative associations of this kind could affect and complicate the high tech orientation of the field with its anthropocentric manipulations. They could displace a purely instrumental attitude towards microbial life, in favour of more respectful approaches that value microorganisms intrinsically. Going beyond their constitution as technological intervention, soil microbial communities may in turn be able to transform the humans who engage with them, thus showing that human are not the only agents who affect and influence. Can admiration for the microbial beings of the earth enable those involved to be altered? How do human/microbe relationships affect knowledge production in the soil microbiome field and the questions microbiologists ask? Are there possibilities for novel and transformative becomings in human/microbe associations, beyond technoscience? How to imagine as well as practice forms of entanglement that do not require or allow proximity?

In order to address these questions I am guided by the 'microbiome people', initially named by Chris, a scientist I interviewed, as implying the 'strange people in white coats that work on microbiome'. As I show throughout the thesis, these strange people can be found also elsewhere, in communities of practice that operate outside the laboratory. They are actors involved in the constitution of soil microbiome knowledge across the diverse fields of policy and growing practices, who inform agricultural methods and food policy implementations while considering the preservation of soil ecosystems. The microbiome people then become all those who have an interest in engaging with microbial communities and are open to the possibility to be affected and altered by microbes. In following the constitution of soil microbiome knowledge across expert fields, the microbiome people show me narratives that contain both productionist discourses focused on human gains and transformative potential for more meaningful ways of relating to invisible lives. These often contrasting dynamics constitute a fragmented, contested and fascinating landscape I seek to delineate in the chapters that follow.

Microbial communities exist silently underground, but they also live and die in labs, on plates such as the one shown in Figure 2. To truly consider and re-establish the intrinsic value and worth of these lives, it is necessary to examine the scientific knowledge and practice created about them and promoted as important to address agricultural and environmental needs. In order to listen to these silent communities, it is essential to investigate the instrumental and technoscientific field that constitutes them in anthropocentric terms. With this research, I hope to convey the sociological relevance of soil microbial communities not only in their depiction as central players in the future of food, but also because this small, underground, invisible life can remind the discipline of the subtle ways in which human exceptionalism emerges unnoticed.

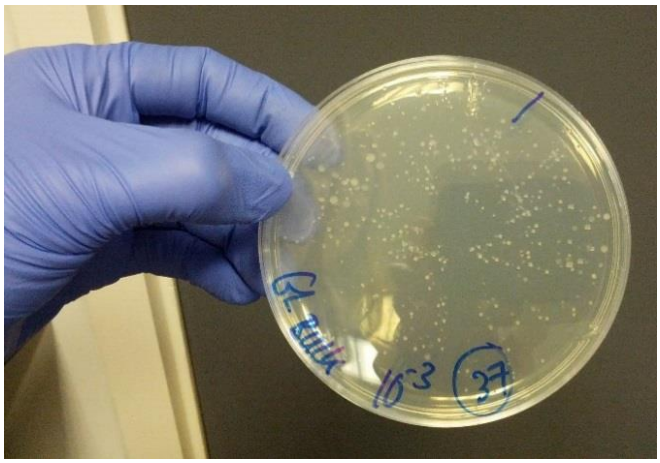

Figure 2: Soil bacteria of the genus Pseudomonas at a UK lab

Structure of the thesis

In the following chapter, 'Humans, microbes and soils', I set out the contribution and commitment of the thesis to a particular scholarship and area of debate. I engage with social science literature concerned with new relationships with the life sciences and note how it mainly engages with the human body to explore the situatedness of biological knowledge and claims. The novelty and contribution of my research is located underground, in the under-researched area of microbial life and soil rather than human bodies. Engaging with emerging arguments around the symbiotic theory of life and the need to consider collaboration beyond the human species, I propose

modes of relating with the nonhuman microbe that recognise its intrinsic rather than instrumental value. In doing so, I argue for a sociology that goes beyond anthropocentric research and instead becomes interested in other biologies and stories. This approach to human/microbe associations can lead to transformative questions amid anthropogenic environmental degradation.

Chapter three, 'Moving microbes', explores the methodological approach of this research and its rationale. The soil microbiome is a multifaceted and moving object of enquiry that cannot be understood from a single site point of view. I therefore outline how a multi-sited ethnography allows me to examine the microbial communities of soil as they travel and traverse sites. This methodological approach leads me to agricultural fields, labs and policy arenas where I research using interviews, document analysis and ethnographic observation. As with the data collection, I approach the analysis in a recursive manner that assists me in tracing the interconnections between fields through thematic analysis. The chapter also considers the ethical choices aimed at protecting the participants' confidentiality, including the decision to omit institutions' as well as people's names for the sake of anonymity. Finally, it engages with my changing positionality across sites and the various shifting of identities occurred in the continuous movement between knowledge spaces.

In chapter four, 'A story of tomorrow', I explore a future-oriented narrative that traverses the soil microbiome field. On the one hand, this tendency presents itself through a fast pace, technoscientific approach that offers innovative solutions involving the manipulation of the soil microbiome. This narrative constitutes the microbial communities of soil as technological tools useful for the implementation of sustainable agriculture. On the other hand, the temporality of the field also emerges as a slower attitude to soil, food and technologies, with a sense that in order to address environmental and agricultural issues currently facing the UK there is a need for fundamental change in agricultural and social practices. In this context, new high tech interventions are considered likely to exacerbate a perceived distance between people and land, a relationship that needs to be re-established. This variation of positions characterises the soil microbiome field as contested and entangled with

wider debates on the place of the human within the environment and the importance of an authentic and direct relationship with soil that rejects the mediation of technological interventions.

Chapter five, 'Ways of knowing microbial life', addresses the circulation of microbial knowledge across different realms of expertise. On the growing side, an ambivalent relationship with science emerges as an acceptance and appropriation of microbial awareness, without entailing an endorsement of the scientific project in its entirety. This means that in the process of translating soil microbiome knowledge into growing practices, growers transform microbial knowledge into their own ways of knowing soil, focused on observation and the use of the senses. Within this modality, soil microbiome knowledge becomes useful in validating the practices in place at these growing sites. In regard to the policy and public realms, in the process of translation, microbial knowledge becomes reduced and 'forced' into trivial oversimplification, a transformation sceptically received by soil microbiologists who are keen on conveying the importance of soil microbial communities but are not willing to reduce the science to the point of rendering it meaningless. This is because for them, microbes have intrinsic values unsuitable to be communicated in policy or public terms. In this context, translation becomes an uncomfortable practice of fabrication and displacement.

In chapter six, 'Becoming with microbes', I explore the relationship between scientists and microbes. I consider how soil microbiologists are unable to 'see' and relate to the microbes they study and how this shapes a detached relationship. Because of their scale, invisibility, short lives and lack of individuality, microbes emerge as specific types of nonhumans, too dissimilar from humans to relate to. Most importantly, what they consider the objective component of the scientific project does not allow microbiologists to engage with microbes beyond a distant relation. Scientists' discomfort around the idea of microbial 'behaviour' emerges as a signifier of the need to delimit microbial agency and strengthen the distinction between human and microbe. Demonstrating once again the non-linearity of this complex field, a coexisting attitude also emerges where more politically and environmentally aware scientists do sense and feel microbes. They describe them

with fascination, consider their needs and even represent their voice in the first person. In relating to microbes somatically through bike rides and drawings, soil microbiologists show that relating is not diminished by small scale or invisibility. When they allow themselves to be affected, these microbiologists 'become with' microbes and are transformed in the way they think and 'do' science, asking questions from a microbial standpoint.

In the final chapter, 'Conclusion', I reconsider the research process and I outline a summary of the key arguments of the thesis: the future-oriented elements characterising this field ultimately related both to an anthropocentric understanding of microbial life and to a wider perspective on the need to reconnect humans and soil; the transformations soil microbiome knowledge encounters when circulating and transitioning across growing and policy fields and the new possibilities of 'becoming' that human/microbe relationships can offer when those involved allow themselves to be affected. I also consider the difficulty of dealing with neglected and invisible lives, in a particularly disputed and nonlinear field. Finally, I discuss the inevitable limitations involved in the undertaking of this research and I propose possible routes for future sociological investigations concerned with the emergence and establishment of soil microbiome studies.

Chapter 2. Humans, microbes and soils

Introduction

My aim in this chapter is to engage with the concepts and approaches that inform this sociological investigation of the microbial life of soil, namely debates around human/microbe relationships and the need for less anthropocentric understandings of life. The chapter first contextualises the emerging soil microbe across fields of expertise, outlining the increasing attention paid to this entity of enquiry in science, policy, growing practices as well as in agricultural and environmental debates. This coming into visibility is permeated by a technological, instrumental and anthropocentric approach to the microbial communities of soil, seen as conduits for sustainable food production. The instrumental element is particularly evident in the proposal of microbial manipulations and interventions deemed crucial to tackle current environmental degradation caused by agricultural practices, an aspect contrasted with that presented in both chapters four and six, where I show the presence of alternative ways of approaching microbial life practiced by growers and soil microbiologists.

The chapter proceeds to illustrate how a number of social scientists have called for a critical engagement with the life sciences that points to the biopolitics of difference at play in the practice of science, a turn I explore in the second section. Biology is now seen as increasingly open to non-deterministic views of life, and in particular to an engagement with the microbial universe. As the life sciences are described as undergoing a shift from determinism to more fluid conceptions of life, recent sociological calls for the need to engage with biology argue that this discipline lends itself more than ever to sociological attention. A consideration of the microbial is seen across the social sciences as possibly offering new understandings and definitions of the human itself. However most of the work taking place at the intersection between sociology and biology primarily focuses on human bodies rather than microbes. By engaging with important scholarly exceptions in this area, I locate the thesis' contribution to the under-researched topic of human/microbe relationships with particular focus on soil, as matters worthy of sociological enquiry.

Only by paying attention to other forms of life, can sociology as a discipline take seriously a decentring of the human from its primary position within the soil community as well as the 'social realm'.

In the final section of the chapter I consider how this emerging literature on microbes and soil, as well as arguments on the embodied nature of science and symbiotic theories of life, constitute the main theoretical commitments of the thesis. Situated within a tradition that challenges the oppressive separation between nature and culture, I hope to extend sociological work in new ways by seeking to articulate an approach that blurs this boundary. I look for this possibility by engaging with the diverse domains and intersection of expertise interwoven in the soil microbiome field. The main argument of the chapter, and one important path of enquiry that runs through the thesis, is that a symbiotic view of the interconnection of life allows for relating to the nonhuman microbe in an embodied and transformative way, beyond an instrumental approach to microscopic life. A repositioning of the human within the soil field as part of the soil community rather than as its administrator can set out the path for a sociology of soil and microbial life that lead to novel human/microbe entanglements. These sensorial relationships may initiate a transformative process of becoming in the scientific questions asked.

The coming to matter of the soil microbiome

In this section I delineate the context of my research located at the intersection of expertise across diverse domains, situating the case for the exploration of the soil microbiome. Interest in soil microbial life traverses a number of diverse fields such as microbiology, agricultural research, policy work, environmental approaches and debates about industrial farming and food production. While my research positions itself within a sociological angle, the multifaceted nature of its object of enquiry requires me to explore these domains to understand the interconnected ways in which the community of soil microorganisms, or soil microbiome, emerges and the kinds of questions posed in scientific literature regarding these communities. I consider this coming to matter 'an event in its own right' (Puig de la Bellacasa, 2014:27), meaning that I examine the 'rise' of soil microbes in science, policy and

farming as a development that requires sociological attention for the fact itself that it is now constructed as important and in need of attention.

The emergence of soil microbial life into visibility is particularly relevant if considering that, until recently, soil has been socially and culturally surrounded by a negative association with dirt. In addition, because processes such as soil degradation and erosion develop over a long time, there is a tendency in public policy to underestimate problems with soil (Montgomery, 2012). An official report issued by the House of Commons Environmental Audit Committee refers to soil as a 'Cinderella' because of its neglect (House of Commons Environmental Audit Committee, 2016:5). For instance, it was only from the early 20th century that soil erosion became recognised as a serious issue (Brevik and Hartemink, 2010). Soil scientists Eric Brevik and Alfred Hartemink argue that in recent decades 'societies dominated by western science' have shifted their attitude towards a connection with nature rather than its domination (2010:21). They consider the emergence of mobilisation in 'soil conservation, soil health or quality, sustainable agriculture, and in soil legislation' as linked to a growing concern and appreciation of soil as an important resource (2010:21). Safeguarding the soil is increasingly considered critical in policy debates regarding the risk of agricultural land 'becoming unprofitable within a generation' (House of Commons Environmental Audit Committee, 2016:34). Discussions about agriculture have also begun to direct their attention to soil health, with columns on the importance of soil and advice on improving soil life abounding across farmers' magazines (Impey, 2018; Jones, 2019; Practical Farm Ideas, 2020) as well as agricultural bodies and institutions (NFU, 2018; AHDB, 2019; Countryside, 2020).

This coming into visibility of soil is underlined by Maria Puig de la Bellacasa, who talks about its 'absence-presence' to point out how soil is now emerging from being overlooked, an event partly made possible by collectives and gardeners invested in relating to soil and its life in new ways, beyond scientific expertise (2014:27). Although soil microbiology has been a relevant branch of soil science since its inception in the 19th century, in the last decade soil science has undergone a move from a focus on physics and chemistry towards biology and microbial life, with an

increase in recurring references to the 'living soil' (Puig de la Bellacasa, 2017). Puig de la Bellacasa notes that 'living soil' as a concept was already popular among radical agricultural circles in the last century, with a prominent book titled *The Living Soil* (Balfour, 1943). However what has changed is how the idea has become mainstream. Céline Granjou and Catherine Phillips also note that in the last twenty years the study of soil has undergone a genomic turn contributing to the recognition of its liveliness at the microbial level (2018).

Soil and agricultural sciences are currently preoccupied with addressing human-related activities such as intensive agriculture[1], seen as implicated in soil erosion and the depletion of nutrients and microorganisms. Methods such as the use of pesticides are identified as affecting organisms living in soil including earthworms and microbes and leaving the soil bare and vulnerable to erosion (Montgomery, 2012). Although soil degradation is a relatively natural geological phenomenon, human practices like deforestation, overgrazing, pollution and ploughing are recognised as responsible for accelerating the process up to a point where the agro-ecosystem could irreversibly collapse (Noble and Ruaysoongnern, 2010). An agriculturally depleted soil also loses capacity for carbon sequestration, with consequences for climate change (Lal, et al., 2007). The current industrial agricultural system is seen as a major contributor to soil erosion and degradation that ultimately causes the land available for agriculture to decrease while suppressing microorganisms (Horrigan, Lawrence and Walker, 2002). This agricultural impact on the soil and the disruption of microbes is considered to have long term effects (Balser, et al., 2010). Among food systems[2] and environmental experts, there is a sense that agriculture needs to be remodelled around more environmentally sustainable practices that can ensure a stable food production while protecting the environment. Chemical solutions such as the use of fertilisers to address soil degradation are currently confronted with the requirement for urgent action to counter pollution and anthropogenic environmental destruction. There is therefore a recognition of the need to find new solutions to address these issues.

[1] A farming approach focused on high crop yield, usually obtained through the use of chemical products (FAO, 2019).

[2] Food systems can be broadly defined as 'a set of activities ranging from production through to consumption' and that also include environmental relationships and outcomes (Ericksen, 2008:234).

Soil microbiome research is one of the approaches emerging in the search for new solutions. Since the word 'microbiome' was first used in 2003 referring to the microbial communities resident in the human body (Nerlich and Hellsten, 2009), microbiome studies have significantly increased in a variety of fields (Knight, et al., 2018). This surge is due to advancements in DNA analysis methods that allow for the study of 'complex microbial communities that inhabit diverse environments' (2018:410). While microbiology has considered the relevance of largely unknown microbial communities for more than a century, recent progress in genetic technologies has contributed to making them more understood (Fierer, 2017).

The soil microbiome comprises 'all microorganisms that can be found in soil' (Fierer, 2017:579). It is the collection of soil microbial communities, made up of a diverse range of microorganisms including bacteria, fungi, protists, archaea and viruses that live in soil environments. These communities are considered highly diverse and unique in their composition and aggregations (2017). In the same way that marine biologists believe that 'marine microbes are central to life on Earth' (Helmreich, 2009:5), soil microbiologists consider soil microbial communities as crucial in all biogeochemical processes and the functioning of the entire earth. Microbes associate and interact with plants and have a number of positive effects including the strengthening of plant immune systems, the provision of nutrients and pathogenic control (Bakker, et al., 2012). Microbes affect all processes of plant life, from germination to development and disease (Raaijmakers, 2015). In turn, they benefit by feeding on the nutrients that plants leave in the soil (2015). The interaction between plants and soil microbiome, essential for the health and composition of both, is a complex relationship influenced by both plant and soil community (Bakker, et al., 2014). In turn, 'microbial communities are highly interactive entities' shaped by soil chemistry, organic material, plant environment, composition and richness (2014:1573). In terms of plant productivity, the function of the different microbes seems to be more relevant than their composition and this applies also to disease suppression where it is the community rather than a single species that determines this ability (Chaparro, et al., 2012). Microbial evenness, a balance where no specific species overtakes others, is also identified as crucial in soil health. Because farming

practices have an impact on microorganisms and their ability to improve soil and crop health, the use of pesticides and industrial chemical fertilisers is increasingly seen as detrimental for the diversity of the soil microbiome while organic agriculture increases the microbial diversity of the soil through the use of organic matter (2012).

The study of the microbial communities living in soil is interwoven with the concern that current farming practices are causing soil and environmental damage to the point of endangering food production. A variety of actors, including academics, companies and agriculture professionals, are looking at the role microbes can play in agriculture (Lugtenberg, 2015a). In the same way that the study of marine microbial death has been observed to come to matter because of marine microbes' role in absorbing carbon dioxide and therefore in climate change (Schrader, 2017), soil microbes come to matter because of their role in agriculture. Soil microbiome research focuses on enabling crops to benefit from particular microbes and on the environmental conditions that allow this to happen (Bakker, et al., 2012). Studying the exchanges occurring between plants and microbes is seen as crucial to address sustainability concerns through the exploitation of the microbiome (Bakker, et al., 2012). Scientists working in this field see the understanding of the microorganisms living in soil as an opportunity to find possible solutions to the problem of soil depletion that affects food security.

The current aim of plant-microbe interaction research is to employ microbes instead of harmful pesticides for relevant applications such as plant disease control, so that agriculture can be more sustainable in the pursuit of increased food production (Lugtenberg, 2015b). The main task is considered to be the identification of 'beneficial microorganisms that can be used as an integral component of future agriculture and horticulture' (Raaijmakers, 2015:412). As many of the microbial processes are not yet known, the task is 'deciphering the plant microbiome' (2015:412) so to 're-shape the rhizosphere microbiome' (2015:413) (concerning the plant root). Beneficial bacteria for growth and disease resistance can undergo genetic manipulation or be added to the soil. Intervening with the introduction of beneficial microbes in the soil is considered useful for the colonization of areas otherwise taken over by pathogens (Chaparro, et al., 2012). The microbiome can be manipulated not

only through established inoculation practices but through genetics and gene expression that can enhance certain functions (Bakker, et al., 2012). The employment of microbes through interventions such as microbial products or manipulations, is seen as enabling the sustainable intensification of agriculture. These solutions are considered needed in order to overcome problems of overpopulation, pollution and diminishing resources (Bakker, et al., 2012). Beneficial microbes thus emerge as the way forward for a shift from intensive to sustainable agriculture that relies less on pesticides (2012). Microbes in this context become the determining factor in a hoped-for transformation from intensive agriculture based on pesticide use and monoculture to one that is sustainable in the long term.

In her work on the transformation of perceptions of soils, Anna Krzywoszynska identifies a current narrative around 'ecological intensification', a process where the management and improvement of soil microbial life allows for the maximisation of production and economic accumulation (2020). For Krzywoszynska, the employment of microbial life aimed at intensification and improvement does not challenge the status quo. On the contrary, it maintains and reinforces a problematic exploitative attitude towards the environment, natural processes and ecosystems, forming 'projects of anthropocentric care' (Krzywoszynska, 2019a:665). Drawing on this critique, I argue that given the instrumental focus of the field, soil microbiome research contains an anthropocentric element where microbes are defined as beneficial or harmful in terms of their impact on food production and thus on the human-centred advantages they provide. This anthropocentric tinge cuts across fields of expertise in shaping the emergence of the soil microbial communities as relevant for human benefit. Beyond scientific research on soil microbial communities and plant/microbe interactions, it is also noticeable in policy narratives around soil health focused primarily on the economic benefits of a healthy soil.

The influence of the ecosystem services framework, established in the 'Millennium Ecosystem Assessment' report (2005), in conceptualising and communicating the value of soils, plays a role in retaining this instrumental attitude. This is the case even within the context of increasing awareness of environmental issues and a recognition of the value of soil and its ecosystems, as I show in the analysis of two policy

documents in chapter four. Ecosystem services are defined as the benefits to human well-being provided 'by the interaction between living (plants, animals, microbes) and non-living organisms (air, water, mineral soil)' (CGIAR, 2014). Soil microbes are seen as able to 'contribute to a wide range of ecosystem services that are essential to the sustainable function of natural and managed ecosystems' including yield increase (Barrios, 2007:269). They are portrayed as service providers and tools, a means to an end valued for the functions they perform. Granjou and Phillips note the characterisation of soil itself as a service provider 'both "living" and "labouring"' and entangled with agro-ecological and economic agendas (2018:394). While the employment of the ecosystem services framework has allowed an appreciation of the value of soils not only in economic terms, it is criticised as a problematic model focused on services and resources for human benefit (Puig de la Bellacasa, 2015; 2017). This is because the ecosystem services model does not consider the intrinsic but merely the instrumental value of soil life.

The profusion of optimism in soil microbiome research, an area of 'progress', 'new technologies', 'state-of-the-art DNA' and 'innovative research projects' (Lugtenberg, 2015b:2) indicates a technological approach and understanding of agriculture and soil where technology is high tech. Because of the importance of soil for food production, this utilitarian approach is permeated by an orientation to the future of agriculture where microbial life needs to be managed, harnessed and employed as required. Large agrochemical manufacturers such as Monsanto are increasingly investing in microbial products, now constituting two thirds of the products used in agriculture, claiming that this work is needed because of the pressure posed by an increasing population as well as environmental damage (Schäfer and Adams, 2015). The involvement of large companies in funding the study of microbial communities raises questions around possible conflicts of interest. It also points to the technoscientific nature of the field, focused on the creation of products, interventions and future solutions. This technoscientific element relies on a strict separation between the humans who research, intervene and manipulate and the microbes who are examined and exploited to benefit food production and alleviate environmental destruction.

This thesis considers the tendency towards a technological fix of agricultural and environmental issues, an important element to explore in the future-oriented field that is the soil microbiome. Donna Haraway has convincingly addressed the issue around the technological fix, particularly significant in debates on environmentalism, science and technology. She shows how technofixes advance the idea that 'technology will somehow come to the rescue of its naughty but very clever children' (2016:3). Instead, she suggests that while technologies can be beneficial, it is through collaborations and more respectful and responsible relations with beings of the earth that it is possible to avoid despair and futurism in all its apocalyptic forms. I argue that these collaborations with different entities found in soil can become concrete practices. These may include for instance the shaping of agricultural fields in ways that mimic forests so to encourage biodiversity and prevent soil erosion, as has been suggested by agricultural researchers (Noble and Ruaysoongnern, 2010).

For Puig de la Bellacasa, soil science in this context is conceptualised as a timeline that goes towards the future and towards production, a problematic 'technoscientific futurity' aimed at economic gains (2015:698). Productionism, the agricultural intensification based on utilitarian efficiency and soil exploitation projected into the future, overwhelms everything else, thus 'advances in science can be questioned, but not a general ineluctable progression to the new or to a "breakthrough"' (2015:697). Arguments against productionism are charged as nostalgic, but considering soil as a community humans belong to is not a romantic return to the past. Instead, it is a reconfiguration of relationships that needs to happen with an awareness of the contemporary global challenges. Puig de la Bellacasa considers her feminist perspective of care that argues for the need of 'making time for soil time' as having political and disruptive implications for ideals of progress and innovation and the reduction of soils to the provision of services (2015:709). If soils can be understood as multispecies and living, certain anthropocentric ideas and a view focused on production can be rejected, thus creating different kinds of relationships that regard soil no longer as a utilitarian resource but as a community the human is part of, the soil community (2015). This is because for Puig de la Bellacasa, humans are part of the soil ecosystem, not their shareholders (2014). In this sense, a consideration of

soils as something to care about has been missing from the scientific debate but while more attention to the soil is needed, the issue is not simply to make soils present and visible but to look at the conditions and consequences of this shift because 'making visible is not a neutral affair' (2014:35).

I consider these critiques of technoscience and arguments around the politics of soil as useful invitations to examine the narrative around the management of microbial communities for human benefits in terms of a future orientation towards sustainable food systems. They also assist me in exploring alternative human/microbe relationalities, beyond anthropocentrism, also present in the field. As I show in chapter four, the technological dimensions of this field are interwoven with specific relations and tensions around future-oriented solutions that manifest both as fast technological fixes aimed at 'conquering' the microbiome and a slower element where microbial experts argue for broader solutions and a reconsideration of food production that takes into account human relations with soil. Questioning a technofix approach to soil microbial life, this thesis puts forward an argument for a decentring and repositioning of the human as a member of the soil community. It now turns to explore how this socioeconomic coming to matter of microbial life has been noted by the social sciences, initiating a debate on the importance to shift the attention to microbes and soils.

A biological turn in the social sciences

In recent years, a number of social scientists have addressed the complex relationship between sociology and biology, with increasing calls for a sociological engagement with the life sciences motivated by a supposed shift from deterministic views of life to more fluid understandings embraced in fields such as epigenetics. Among these, Elizabeth Wilson argues for a feminist re-appropriation of biology for what biological insights can 'do to' feminist approaches, in other words for their transformative effects (2015). In this sense, she urges feminist theory to overcome its antibiologism, a tendency justified in the past but no longer tenable, and to reconnect with the human body in a way that can open the possibility for a 'gut feminism'. Anne Fausto-Sterling argues against a static distinction between a taken

for granted sexual difference and gender, considered changeable and politically constructed (2000). She suggests instead that not only gender, but also biological accounts of human sexuality are grounded in political and social contexts that are in turn embodied. Nikolas Rose also urges the social sciences to put an end to a neglect of biology, justified by a rejection of what was considered a deterministic view of life, but now no longer acceptable because of a supposed transformation taking place in the life sciences where past reductionisms have been left behind (2013). In this sense, Rose calls for an 'affirmative relation' with the life sciences that allows a conversation and critical engagement with their claims and understandings (2013:23). Similarly, Maurizio Meloni, Simon Williams and Paul Martin address the complexity of the relationship between sociology and biology and identify a shift in biology in terms of a development and interest in more fluid understandings of species boundaries, epigenetics, symbiosis and microbiology (2016). They argue that because of these developments, a separation between disciplines is increasingly under question. In a rather more critical fashion, Troy Duster warns sociologists that because they have been too preoccupied with discursive discussions on the social construction of reality, their neglect of crucial developments in biology and genetics has allowed racialised characterisations to enter the scene undisturbed (2015). This is why, Duster argues, it is essential for sociologists to turn their attention to the study of science.

These calls for a sociological engagement with the biological sciences (with varying and often contrasting degrees of 'friendship' between disciplines) focus on the social dimensions, practice and situatedness of these fields of study. When looking at the relationship between sociology and biology, these scholars advocate for attention to be paid to the definitions and the politics of difference advanced in the biological sciences, with a concern for human bodies rather than other life forms such as microbes. These arguments represent the starting point of my theoretical path, but because my study aims at going beyond a purely human terrain to propose a less anthropocentric engagement with the life sciences as well as to invite the possibility of a decentring of the human, I must also consider literature coming from a variety of spaces that call for these nonhuman engagements. The discussion requires me to

step into a more interdisciplinary framework, going beyond the strict field of sociological research to examine work in other social sciences and humanities, with authors who are noticing the emergence of the study of microbial life linked to advances in genetics and molecular biology.

Work specifically focused on the microbial soil realm is scarce and recent but especially relevant for this thesis. It includes Granjou and Phillips' study on the nature of human/nonhuman relationships among French soil and microbial ecologists (2018). Granjou and Phillips find a 'promissory agenda' in regard to the use of microbial organisms 'for agro-ecological purposes' (2018:394). The notion of promissory science, employed in science and technology studies, has been defined as 'a discipline that exists more in the speculations and promises of its supporters than in terms of scientific results and marketable products' (Hedgecoe, 2004:17). Promissory science is about the creation of expectations and optimism around the development of technologies and scientific innovations. Among the scientists they interview, Granjou and Phillips find this optimism and feeling of enthusiasm for the potential for discovery alongside a form of helplessness for the complexity of the field (a convolution I show in chapter five to be relevant in the tensions around the translation of this knowledge into policy recommendations). The microbial ecologists studied by Granjou and Phillips have a vision of a new agro-ecological future that uses soil microbes for human purposes, a future agricultural revolution where microbes play a role. Granjou and Phillips also note a shift where microbes are now acknowledged for their assistance rather than mere threat to human life, as underlined by anthropologist Heather Paxson. They use her concept of microbiopolitics (to which I return later) to look at how soil microorganisms are seen as linked to agricultural aims. Granjou and Phillips argue that these relationships are production-based and human-centred, but they also offer an opportunity to explore different types of soil entanglements, precisely the human/microbe relations I set out to explore in the following chapters. In looking at the transformation undergoing soil labour in England and the logic of soil improvement, Anna Krzywoszynska argues that soil labour has been passed on from humans to microbes and that farmers are shifting from tractors to soil biota and therefore are still aligned with a productionist

approach to soil as a means for food production (2020). Krzywoszynska also considers the complexity of farmers' care for soil life, where farming and livelihood may have a different, contrasting temporality to the needs of microorganisms (2019a). I find particularly useful her call for redistributing care for soil ecosystems so that the burden does not fall on farmers alone but is reconsidered in the wider food system. I discuss in chapter five how growers negotiate their knowledge of soil microbes and practices to improve the soil with an ambivalent relationship with the scientific project.

Kristina Lyons on the other hand explores soil/human relationships in soil scientists and farmers in the Amazon, interrogating the everyday practices and transformations of people and ecologies' living conditions, from trees to insects and microbes (2014; 2016). Hannah Landecker studies antibiotic resistance with the awareness that antibiotics come from soil bacteria (2015). She proposes the concept of 'biology of history' that should be considered alongside the history of biology in the way 'human historical events and processes have materialised as biological events and processes and ecologies' (2015:3). The biology of history draws attention to how human medical and industrial interventions have wide ramifications that can be read in bacterial change and increased resistance. Because antibiotics come from the soil, so does their resistance. With these insights on the material alongside the historical nature of bacterial changes and the interplay between history of biology and biology of history, Landecker points to the social dimensions of soil and microorganisms.

I read this work on soil microbial life also in connection with a broader field of research that initiated sociological attention to microbial life more generally. This allows me to consider these interventions in their effort to expand the remit of sociology (and other social sciences) to the biological domain. In this context, Myra Hird makes the problem visible by engaging interdisciplinarily with the late biologist Lynn Margulis. Hird underlines the neglect of microbes in the social sciences and proposes that microbiology can 'inform sociological analyses of ecology' (2010:738). She links the microbial oversight to the nature/culture separation still dominant in sociology, which means the discipline is only able to engage with environmental

debates unilaterally rather than reciprocally. Drawing on the work of Margulis on symbiosis (to which I return in the final part of the chapter), Hird argues that the idea of microbial coevolution with other organisms can ultimately allow the overcoming of the separation 'between matter and culture' (2010:740). Anthropologist Stefan Helmreich on the other hand looks at marine biology and the study of microbes living in the depth of the ocean (2011). His intervention, based on fieldwork with marine microbiologists, examines the complexities and challenges they face in defining species, genealogies and the origin of life through DNA technologies. Helmreich sees these complexities as a possibility for 'displacing humans as the only ends of evolution' (2011:688). A recent social science study also explores the microbiome of people's kitchens in a citizen science project based in Oxford (Lorimer and Hodgetts, 2017). The study aims at understanding people's knowledge and perception around the kitchen's microbiome (Hodgetts, et al., 2018). Calls for an increased attention to microbes have reached disciplines such as the philosophy of biology, with John Dupré looking at organisms as communities that share selection and evolutionary destiny (2012). Dupré is interested in updating his discipline with recent shifts and transformations occurring in biology that have important implications for the answer to his main problem of defining an organism. Because of the microbes living in the human gut for instance, the boundary between outside and inside the human body is no longer considered fixed.

Most relevant to this thesis, anthropologist Heather Paxson (2008) proposes the concept of microbiopolitics drawing on Michel Foucault's notion of biopolitics (1978), the government of populations and management of life performed through institutional and statistical techniques of power. As an expansion of biopolitics, microbiopolitics considers life beyond the human to include microscopic microbial communities as a further category in need of regulation. Paxson analyses the microbial life of cheese through the concept of microbiopolitics in order to understand how social regulation mediates the relationship between humans and microorganisms and manages cheese's microbial life in the name of safety concerns (2013). Bruno Latour had documented the Pasteurian recognition of the presence of microbes, agents that proliferate and cause disease and death, the becoming-visible

of the 'evil entity' (1988:107). Following this Pasteurian understanding, Paxson describes the current coming to matter of post-Pasteurian perceptions of the microbial (2008). These attitudes resist characterising microbes as merely dangerous, to consider them as allies and collaborators, and are found among artisanal cheese makers who need microbes for their products to acquire nutritional value and taste. Paxson argues that exploring microbes can ultimately illuminate 'the human "itself"' (2008:19). This is because post-Pasteurian cultures allow for an appreciation of the intimate association between human and microbe, as shown for instance by the significant presence of microbial genes in the human gut.

Paxson's microbiopolitical proposal assists me in exploring the management approach employed in soil microbiome research where microbial life is seen as in need of control, harnessing and manipulation for agricultural purposes. Through a microbiopolitical lens it is possible to see soil microbes as regulated in their composition, quantity and functionality. The use, government and management of soil microbial populations appear then to recognise these organisms as allies but remain human-centred in their endeavour. Soil microbes are considered able to assist in the process of making agriculture more sustainable, but also in need of intervention, enhancement and control of the right dosage, quality and distribution.

I locate these engagements with the microbial domain and their making microbes a concern for the social sciences, as the main theoretical commitment of this thesis. The different fields and conversations that provide the scholarly and disciplinary ground of my research therefore include debates occurring in sociology, science and technology studies as well as broader discussions across the social sciences concerned with more-than-human relationships. My contribution to the existing conversation is an invitation to question anthropocentric social sciences focused on the human body and go beyond the boundaries between nature and culture and between the social and the life sciences. I argue for a sociology that includes different biologies and microbiologies and encourages a reconsideration and repositioning of the human as part of the soil community *with* the microbial.

This endeavour also draws on the nonhuman turn which occurred in recent decades in the social sciences, with increasing attempts to expand disciplinary realms beyond

a focus merely on the human, instead arguing for more attention to be placed on nonhuman entities. Initiating this shift, Donna Haraway has long declared the dualism between human and animal as finally 'breached', together with the separation between nature and culture (1987:4). Haraway considers the transgression of these boundaries as a political move overturning the categories of animals, women and non-whites, constituted in the West as 'lower' groups. The nonhuman shift then entails the dismantling of the innocence of the category 'human' (1987). By constituting a group that is separated from others and from nature, Haraway sees human exceptionalism as narcissistic self-centredness and self-certainty that excludes interspecies interconnections and partnerships (2008). Human exceptionalism is therefore the dominion of 'man' over nature and all its critters for human benefit (2008). By asking 'how do the differently situated human and nonhuman actors and actants encounter each other in interactions that materialize worlds in some forms rather than others?' (1997:130), Haraway shifts the focus from 'man' to the significance of what are now referred to as more-than-human entanglements[3] and associations. She therefore brings 'the relationalities of us with that which isn't human' into the conversation, thus challenging human exceptionalism (2006:141). Specifically, Haraway's proposal entails telling the encounter with different species and critters, including her dog and racing pigeons (2006; 2016).

Unlike Haraway, in his contribution to the nonhuman shift in the social sciences, Bruno Latour emphasises the agency of things rather than the association with other species and life forms. Latour considers how 'the nonhumanity of Nature' has been separated from 'the humanity of the social sphere', thus maintaining human and nonhuman life strictly distinct (1993:31). He regards this division as interrelated with the dichotomy between past and future and modern and ancient. If modernity implies the overcoming of a past and the emergence of both the human and the nonhuman other, science is what distinguishes them, allowing an asymmetry where

[3] The concept of entanglement indicates specific relationalities that transcend a distinction between separate entities who then become involved with each other (Barad, 2007). Instead, entanglements concern interconnections predating the separation, where one entity cannot exist without the other. Entangled entities are therefore 'mutually constituting one another' (2007:389).

the West is seen as different from everything else while the rest is constituted as similar to each other and unable to separate nature and society (1993).

This is why for Latour, a sociology merely focused on the 'social' ignores the ways in which human and nonhuman actors affect this assumed realm (1988). The discipline is therefore unable to learn about them, 'deaf to the lessons of the actors themselves' (1988:40). Latour proposes instead sociologies that are reshaped towards the examination of real objects, collectives and humans in conjunction with things, rather than remaining 'imprisoned in social representations' of a static social and merely attributing symbolic meaning to immutable (natural) forces (1993:90). Bringing the nonhuman back for Latour entails an emancipation 'from the double domination of society and science' (1988:150). Then nonhumans can emerge in the story, effectively a tale of nonhumans. By employing equal definitions and terms to address both humans and nonhumans, Latour hopes to counter the 'asymmetrical treatment of human and nonhuman actors' (1988:262).

Anthropocentrism and the assumed uniqueness of humans in this sense can be located at the very foundation of sociology, a discipline that shows signs of disdain in its refusal to engage with nonhumans (Irvine, 2007). For Leslie Irvine, the arrogance stems from a concern that the inclusion of nonhuman life could undermine the exceptionality of the human. This manifests in the justification sociologists engaging with species are still required to provide in order to make a case for their lens (2007). An anthropocentric sociology entails, therefore, the erasure of perhaps the ultimate minorities, the most invisible groups. It provides a unilateral account of a 'social world' that is removed from interconnections and that ignores the ways in which other agents influence, affect and constitute relationalities with and beyond the human.

The asymmetry of the treatment, the double separation human/nonhuman and society/nature and the domination of science emerge as constitutive of anthropocentric thought, literally the locating of 'man' at the centre of the story. This primary position entails the erasure of those residing in the non-central, the peripheral and inferior nonhuman. It also allows an exploitative and management attitude in the scientific study of nonhumans. The relegation of the nonhuman other

to a lower, insignificant and passive domain, grants implicit permission for the scientific manipulation of entities constituted as mere services for human benefit. Regarding the human as the exception and the centre of all stories entails also the killing of enormous amounts of nonhuman beings for the sake of 'crafting scientific facts' (Haraway, 1997:xviii). Far from constituting a mere disciplinary shortcoming, anthropocentrism has therefore wider implications in human/nonhuman relations and specifically in the constitution of knowledge and the devising of scientific research and research questions. Only by acknowledging human exceptionalism it is possible to consider that humans are not the only actors but 'animals take an active part in the knowledge that is produced about them' (Despret, 2015:100).

While, as discussed, sociology has not been ready to consider nonhumans as part of its domain and as agents who engage in relations (Carter and Charles, 2018), other disciplines have begun to take the nonhuman seriously. Geography has proposed attempts to 'rework prominent concepts in human geography to support the nascent field of animals' geographies' (Lorimer, Hodgetts and Barua, 2019:27). These have focused on addressing the category of 'animals' rather than human accounts of them (2019). In philosophy, Vinciane Despret has interrogated animal subjectivity, intentionality and agency (2008, 2013). Her engagement is instigated by a discomfort with the way in which the pronoun 'we' is used in disciplines such as philosophy, sociology and psychology to imply humans who know better and underline their exceptionality and difference (2008). She began therefore telling the story of the concrete and 'living presence' of nonhumans from their standpoint and the becomings together between humans scientists and nonhuman animals (2015:99). This entails bringing animals into philosophy not as abstract ancestors or as 'others', but as a real presence infused with transformations and temporalities. In this way, Despret expands her philosophical practice following an obligation to involve animals, thus overcoming the compromise of distance and the boundaries, both disciplinary and political, between distance and proximity and between human and nonhuman (2015).

My investigation of particularly neglected living forms and of the entanglements that emerge with and through them, is informed by these critiques to human-centredness

and the belief in the uniqueness and superiority of the human. Drawing on these arguments, my research poses itself as an instance of a sociology that takes the nonhuman seriously, a discipline that overcomes anthropocentric self-importance and invites relations with the nonhuman to emerge and count. While the nonhuman shift in the social sciences has often involved visible entities and large animals, thus emphasising the importance of the visual sense for an engagement with the nonhuman, my work sits in the invisible, the not seen and therefore neglected, pushing sociology further in the recognition of the nonhuman. It is a contribution to the nonhuman turn that goes beyond species, to embrace multi-domain encounters. Within the broad definition of that which is not human, I invite the microbe to enter the disciplinary field of debate and propose the specificity and relevance of this invisible life form residing underground.

In calling for a sociology that looks beyond its anthropocentric gaze, I join other sociologists who have for decades invited the discipline to 'take up the animal challenge' (Carter and Charles, 2018:79). Like them, I argue that a number of life forms beyond the human are entangled with each other in ways no longer possible to ignore. I also agree with the proposition that to engage with nonhumans is not necessary to desert the discipline and look elsewhere. It is instead possible to abandon the anthropocentrism that characterises much of sociological research, so to allow other 'others' to enter the discussion. Similar to studies that take into account marginalised experiences marked by the social categories of race, gender, class, I focus on the less considered lens of species and in particular on unnoticed entities like soil microbes. If one of the strengths of sociology is to shed light on neglected groups and discriminatory practices, I argue that the microbial communities living in soil deserve particular attention because of the multitude of invisibilities that constitutes them as specific life forms not necessarily fitting well within the broad notion of 'nonhuman'. Whilst I argue that soil microbes are sociologically relevant however, I do not propose their 'elevation' from the realm of nature to a supposedly superior social domain, nor do I invite the human to declare its biological corporeality and 'descend' to the natural world. What I do argue is that these realms are not distinct, that microbial and human life are entangled and so are

their spaces and histories. This thesis is therefore also indebted to Bruno Latour's problematisation of the meaning of the 'social' and his definition of sociology as the '*tracing of associations*' concerned with connections and reassembling across fields of practice rather than with a specific realm (2005:5). In particular, I am interested in making the tracing of connections and associations within the soil microbiome field sociologically pertinent.

The thesis draws on these varied sets of literature to extend them into a novel space of human/microbe relationships developing within soil microbiome research in the UK. I look particularly at the creation and employment of soil microbiome knowledge beyond the scientific laboratory, considering the intersection of expertise including small scale growing practices in order to examine the microbial event at work. My aim is to explore the related layers of competence involved in the 'knowing' of soil microbial life that contribute to the coming to visibility of this field of study.

In the following section I propose a more speculative invitation that runs through my research, for alternative and transformative microbial entanglements. I consider whether the instrumental interest for soil microbes can leave room for other routes and associations aside anthropocentric approaches to natural processes. I interrogate whether there are possibilities for transformative becomings in human/microbe relations, within and beside the conflation of science, technology and society that is technoscience and that often entails exploitative and anthropocentric relationships with other life forms. In this sense, while recognising the productionist nature of soil microbiome research, my investigation does not focus on particular concepts such as microbial labour as an analytical lens for the examination of more-than-human relationalities, as I am interested in allowing the emergence of texture, nuance and complexity of human/microbe associations among scientists, growers and policy practitioners. Can admiration for the microbial beings of the earth enable those involved to be affected? How do the microbiome people practice a horizontal view of human existence within the soil community and how does this affect their relationship with the environment so that soil microbes become agents in the research process?

Microbial entanglements

Microorganisms living in soil emerge as particular kinds of nonhumans, located at the boundary between life and nonlife and therefore a problematic entity to define, a life that leaves 'the domain of the given into the contingent', to become a scientific practice (Helmreich, 2011:674). For Helmreich, this means that 'life' is no longer a straightforward biological object but a fading concept pervaded by biotechnology possibilities and unpredictable genetic transformations. Specifically in the microbial realm, what does living mean when life is reduced to a function performed by a community? The challenge of relating to the invisible is accompanied by the large numbers of microbes in a given environment, which means they are never referred to as single individuals and rarely as a species. It is the community, rather than single individual microbes, that emerges as relevant for the function that is seen as performing collectively. In this context, I argue that 'knowing' microbial communities means being able to transcend invisibility and individuation and go beyond theoretical conceptualisations, to involve experiential types of connections that rely on the senses. But how can minuscule, unseen entities be sensorially experienced? What kind of relations with microbes and the microbial realm are possible? Not only are microbes invisible, they are also constituted as distant entities by a science that epistemologically rejects an embodied relation with its object of study in favour of a rational, factual and objective approach to the natural world. In this thesis I suggest that bodily engaged relations with microbes are needed (and even present for some of my participants) precisely to challenge the abstraction of their existence and the problem of relating to them.

Circulating across different fields, soil microbiome knowledge becomes entangled with a dimension of touch that enables those involved to sense microbes through sensing soil and becoming interested, a point I explore further in chapters five and six. Describing a cartoon depicting a genetic scientist 'twisting his body into the shape of a double helix' Natasha Myers argues that 'he uses his body to reason' (2015:1). Myers explores how protein modelers use their bodies to know their object of study both in a kinaesthetic as well as affective mode because 'life science research is a full-bodied practice' (2015:2). Her fieldwork with protein crystallographers building

models of proteins shows a performative, not only visual nature in science where 'modelers' moving bodies and their moving stories are integral to scientific inquiry' (2015:5), thus revealing its 'affective entanglements' (2015:6). To build three-dimensional models, scientists involve their body therefore introducing an embodied element in the creation of molecular knowledge. These models are performative because they tell a particular story, they 'act as proxies, speaking as and for molecules' (2015:19). As a result, 'modelers get *molecularized*' (Myers, 2015:109). In a related manner, recounting the story of a German horse, Hans, who was able to answer mathematical questions correctly tapping his right foot, Vinciane Despret shows that the horse had educated and affected human bodies so that he could read unintentional body cues from his questioners, making them perform movements that they were not aware of themselves (2004). Human bodies were thus transformed through a reciprocal influence and affection.

This thesis is open to the possibility that also invisible microbes may be training their investigators to be in tune with them, be transformed and 'disclose new forms of "being together"' (Despret, 2004:122). In thinking with what Despret calls the 'miracle of attunement' (2004:125), humans affected by microbes become 'microbes-with-humans' because they become interested. Following Myers and Despret therefore, the question of how human bodies can be affected by microscopic organisms can be addressed by considering body activities that do not need to entail touch or sight, but are entangled with microbes through the thinking and feeling about them as inhabiting the soil humans also live on. There is no need to touch microbes if one can touch the soil, while touching soil also means touching microbes without realising it. The microbial universe can thus be known by expanding intellectual knowledge to kinaesthetic involvement. Sensorial experiencing of soil microbes is then possible without seeing, breathing or touching *them*, but through an embodied relation with soil, now become a proxy that speaks for microbes too.

But what does a human/microbe relationship look like in *practice*? And how can relating to soil microbes transform the scientific questions asked? Astrid Schrader suggests that overcoming the hierarchy of difference with nonhumans that implies human priority, as well as 'becoming troubled' by them (2015:20), may be the first

steps in the transformation to '*begin* to care' (2015:4) because what matters is that scientists start to 'listen to trouble' (2015:21). If scientists can 'listen to' the instrumental exploitation of microbes, this practice can lead to becoming affected. Without the need to choose a priori who is worth trouble and time, microbes can become those that require an attentive listening, thus becoming those that affect. To explore further this call for transformative scientific practices, I appeal to authors who examine the interrelation and coevolution of humans and microbes, as if this knowing can translate into a more profound appreciation, respect and even admiration for these invisible organisms and in turn be able to reposition the human in the soil field as one of its members. Far from attempting to bring the human back to centre stage, I examine human/microbe entanglements with the awareness that to start illuminating other beings requires humans to change and transform the way they see themselves as much as microbes.

To develop this argument I undertake a slight digression through the plant biotechnology field, engaging with authors I encountered when researching the interaction between plants and microbes. To justify the use of genetically modified crops in agriculture, plant biotechnologists Dulce Eleonora de Oliveira and Marc Van Montagu argue that genetic changes happen regularly across living organisms in terms of genome silencing or activation and despite the taxonomies in use 'species often have indistinct boundaries', for instance through gene transfer[4] (2015:140). Similarly, plant scientist Inge Broer questions 'the integrity of a being and of its genome' arguing that genomes are constantly prone to changes (2015:150). I particularly welcome these arguments around the blurry boundaries of species, but not necessarily in the way meant by these authors, who question conventional taxonomy only for the brief moment needed to advocate genetic technology. To take the argument further would mean to suggest for instance that if species exchange genes and are interconnected, then humans, animals, plants and microbes are all worthy of attention and protection as collectively constituting the soil community, but for this conceptualisation I have to turn to other directions.

[4] The capacity to acquire 'sequences from distantly related organisms' (Ochman, Lawrence and Groisman, 2000:299).

By telling the story 'of the nonhuman ancestors', of microbes that come 'before campfires, before proclamations of independence, before cities and urban sprawls' Lynn Margulis, writing with her son Dorion Sagan (2002:xvi) makes clear that 'we come from symbiotic microbes' (2002:127), defining symbiosis as 'simply the living together of organisms that are different from each other' (2002:12). Because of these associations there is no such thing as an independent individual; bacteria come before species because they have no species, 'taxonomy ... is thus artificial' (2002:65). For Margulis, animals and plants cells (eukaryotic) have 'multiple ancestry', meaning that they derive from bacteria through symbiosis, which is a microbial association (Margulis, 1981:5). Symbiotic theories, recently reasserted by authors such as Donna Haraway, have often been dismissed and even ridiculed by the scientific community and Margulis was aware that 'some may feel belittled' by a view of life and evolution guided by microbes, but she argued that there is no need to be humiliated if microbes determined and shaped subsequent evolution through fusions and acquisitions (Margulis and Sagan, 2002:204). When Margulis claimed the role of microbes in evolution and as our ancestors, she pointed to the politics of a human stripped of its protagonist role in the story of life. As I show in chapter six, this awareness can mobilise a set of considerations that problematise the centrality, individuality and exceptionality of the human and open the possibilities of an approach to soil and the life within that challenges this focal point, thus allowing other entities including microorganisms and plants to enter the field of debate. The exploration of these possibilities, or as Helmreich proposes, the symbiopolitics of power relations at play between 'entangled living things' (2009:15), ultimately makes microbial life a contested field in need of sociological engagement. By bringing a critical account of marginalised experiences to the microbial realm, sociology could transform itself in the process, towards a less human-centred discipline.

Having studied Margulis, Haraway argues for the need to find kin and make collaborations with others that do not need to be humans nor share similar ancestry or family (2016). Haraway embraces the idea of multispecies and the notion that we 'become-with each other' (2016:97) because 'the name of the game of living and dying on earth is a convoluted multispecies affair that goes by the name of symbiosis'

(2016:124). Biology is not neutral but a historical and situated field embedded in Western notions of race, species, sex and Haraway calls for the transgression of boundaries and dualisms such as humans/animals and culture/nature as a form of political resistance to interlinked modes of oppression of women, animals and other 'others' (1987; 1997). This means also abandoning anti-science ideologies to resist and go beyond the dualisms of domination that also separate nature and culture (1987). Haraway connects this resistance to dualistic thought to the question of what we are when we are in touch with other animals, a question that challenges the separation between humans and animals. Haraway responds to this dualism with the concept of companion species as a 'pointer to an ongoing "becoming with"' where kin from different places can interrelate (2008:16). Haraway is interested in the 'myriad of entangled, coshaping species of the earth' (2008:5) because 'every species is a multispecies crowd' (2008:165). Human exceptionalism becomes questioned in this conception, because the human itself is not singular but a community, a partnership of tools and other beings (2006). For Haraway, 'good scientists have a way of nibbling away at prejudice with mutated questions and lovely data' (2008:34). In my quest for alternative entanglements between experts and microbes I particularly look for this defiance of prejudice not only among scientists, but also policy advisors and growers. In the chapters to come, I hope to show that when humans engage in relationships with the soil microbial communities, this partnership can become transformative in the way they see the world.

Conclusion

In order to contextualise the coming to visibility of soil microbial communities across realms of expertise, I have outlined some of the main approaches, questions and claims advanced in science, policy and agricultural debates. Because of their association with plants, the microbial communities living in soil are increasingly recognised as offering a possibility to shift farming practices towards sustainable food production. The microbial event is also noticed by the social sciences where a perceived shift away from genetic determinism and towards more fluid understandings of life motivates calls to engage with the biological domain. A

number of social science scholars are increasingly attributing relevance to the study of biology but to date they have primarily focused on the politics of the human rather than on nonhumans such as microbes or soil. While their work is one of the starting points for my study in their bringing the politics and situatedness of biology to visibility, my contribution aims at shifting the attention from a human-only domain and consider the life of microbes as significant and worthy of sociological attention.

This study is therefore located in an under-researched area, positioned literally underground, in dialogue with scholarly endeavours on soil and microbial life. The novelty of my research is taking the work on biology and society and expand it to the study of intersecting forms of expertise in the soil microbiome field. In this way, I propose a sociology that moves beyond anthropocentrism to consider other biologies, stories and biographies. A multispecies call for resistance to oppressive dualisms, emerging arguments around the politics of soil as well as sensorial contributions to the exploration of entanglements with the nonhuman constitute the intellectual drive that informs this proposal of a sociology of soil and microbial life. In identifying and problematising a technological and anthropocentric element in the current approach to the soil microbial communities, I set out the theoretical proposal of this thesis and its contribution to a tradition that explores multispecies relationships in order to go beyond the strict human/microbe separation and allow for a decentring of the human and its reposition within the soil community. It is in countering a solely high tech approach to the field and in exploring the microbial event as an opportunity to learn in new ways the human/microbe association that I propose my contribution to these debates.

The soil microbiome is co-produced as a specific kind of nonhuman life, an existence that goes beyond species categorisations and comes to matter in its mass potential rather than the individuality of its multiple members. Its ineffable nature requires different modalities and forms of relating to the unseen that can counter the abstraction. This invisible living entity can then be understood and 'known' through the senses, in transformative embodied relationships that take place when those concerned with the microbial world allow themselves to establish an association with microbes and to 'become with' them. These sensitivities and possibilities of

becoming may be able to transform human/microbe entanglements beyond a purely instrumental and exploitative approach, to propose that microbes matter for their intrinsic rather than instrumental value. In researching microbial communities and associations, symbiotic theories can assist in repositioning the tale of 'the social ape who walks upright' and does not recognise the lives and actions of its most important ancestors (Margulis and Sagan, 2002:xvi). Instead, shifting human/microbe entanglements in the recognition of close coevolution may lead scientific questions to turn to new directions that take into account microbial life beyond an anthropocentric and instrumental approach. The main argument of this chapter, and of the thesis, is ultimately that the soil microbiome field is more than productionism. It is more than agricultural labour, more than technoscientific exploitation, economic growth or futuristic advancement of the food system. The field comprises all of these elements, but it also entails relationships that are continuously reimagined in transformative potentials for the way humans/microbes experience and affect the world. In the contested field of soil microbial life, my attempt to stay with the trouble entails allowing the complexity to unfold in the chapters that follow.

Chapter 3. Moving microbes

Introduction

This chapter discusses the methodological approach adopted in this study and its rationale, a step that allows me to define more clearly the object of my research as the knowledge produced about soil microbial communities, or what I often refer to as 'the field' throughout the thesis. It considers how the intersections of competencies involved in the formation of the soil microbiome in the UK landscape constitute a multifaceted entity not understandable from a single-space standpoint. I therefore undertook a qualitative multi-sited ethnography to examine these interrelations of expertise and sets of interests. The scientific, growing and policy realms emerged as important sites in the formation of soil microbiome knowledge, and multi-sited ethnography allowed me to move between these interconnected spaces. This methodology enabled me to engage with my object of study, the constitution of soil microbiome knowledge, from different angles, thus experiencing the perspectives and challenges of the actors involved in the constitution of the soil microbiome as an object of study. My fieldwork entailed a number of ethnographic tools necessary to explore a complex and disputed field, from participant observation to interviews, from laboratory and farm visits to document analysis and visual data. In the attempt to trace the interwoven spaces involved in the formation and circulation of soil microbiome knowledge, I carried out both the collection and the analysis of the data in a recursive manner across areas of expertise, rather than approaching science, policy and growing practices as distinct categories.

After considering the rationale for this methodology, the sites explored and the data analysis process, I proceed with some ethical discussions on the decisions taken to protect and respect participants' confidentiality in the relatively confined field that is soil microbiology in the UK. I conclude the chapter with an examination of my positionality and intervention in the field that ultimately contributes to the constitution of the soil microbiome as an object of study. In looking at my own investment in the microbial soil, I therefore acknowledge that a methodology is constructed and affected by the situated position and the sets of interest the

researcher holds in society. It is in this sense that this research is not merely about the acknowledgment and interpretation of a multifaceted phenomenon but it includes a contribution to its production. I argue that this awareness is what makes knowledge ultimately accountable.

A multi-sited ethnography

As discussed in the previous chapters, microbiomes are complex microbial communities 'combined with a host or environment' (Microbiology Society, 2017:3). My initial interest originated from a curiosity around the gut microbiome, the microbial communities living in the human digestive system. Beside the human gut, I soon became aware of the surge of research on a number of diverse microbiomes, from oceans' to built environments'. This is when the specificity of the microbial communities living in soil, in their interconnection with agriculture as well as their relatively unknown nature, presented itself in my research path. Thus, the microbial world itself had initially greater significance in my research than the specific environment I set out to study. This priority affected the evolution of my methodology.

As microbes are life forms primarily known as scientific entities because of their invisibility to the naked eye and therefore their inaccessibility to wider publics, it is the scientific world that I initially considered as the main site for my investigation. I acknowledged the importance of examining 'tribes of scientists' (Latour and Woolgar, 1986:17) and analysing the daily practice of science and the dynamics unfolding in laboratory settings to understand how these contribute to the construction of scientific facts. When my focus shifted from human gut to soil however, also the initial attention to the practice of science as the 'site' to study evolved into a recognition that the soil microbiome is constituted by a plurality of epistemological spaces. Escaping the boundary of science, soil microbiome knowledge is entangled with and co-created by other fields and domains such as growing practices and policy making; it therefore affects and is in turn influenced by policy and agricultural debates. This field takes shape in a multitude of arenas across

the scientific, regulatory and agricultural realms, thus the parties involved in its formation are not limited to the scientific laboratory. It became clear that the soil microbial communities are strongly intertwined with an agricultural plan related to food security and recognised sustainability needs in farming practices. Beyond scientists, those involved in policy work and agricultural fields are implicated in the co-production of soil microbiome knowledge.

With this understanding, my science-centred focus needed to expand and include growers and regulators as crucial actors in the constitution and definition of the field. With farmers and policy specialists becoming increasingly aware of the importance of the biology of soil, the exploration of this area of study brought me to broader spaces of knowledge formation. The specific field of microbiology that is microbiome studies itself had to expand towards soil microbiology more generally. In this sense, while exploring the soil microbiome with the 'microbiome people', those most involved in this area of research, when engaging with growers and policy experts the thesis at times goes beyond pure microbiome research to refer to the microbial life of soil more generally.

In identifying domains involved in tracing and unravelling the complex layers of the soil microbiome event (the coming to matter of soil microbial communities), like Charis Thompson I was interested in 'evolving, fractured, competing, animating scripts of the field, not the scripts that structured the dominant debate' (2013:11). In the multiple spaces of soil, some debates are more visible than others while some stories are obscured and left waiting. This awareness led me to identify actors and territories beyond the dominant narrative around the soil microbiome. While the scientific realm remained essential in the formation of the soil microbial communities as an object worthy of attention, the regulatory sector appeared as a possibly competing force in the scene, whereas small scale growers with an ethical sensitivity seemed to represent the unheard and minoritarian voice in the construction of the field.

Some of the soil microbiome literature seems to consider farmers as the receivers of scientific findings on the employment of microbial communities. Scientists involved in microbiome research talk in terms of the implications of their data for farming

practices, arguing that 'agriculture should consider maximizing the coadaptation between plants and microbes', thus implying that farmers need to change their practices accordingly (Chaparro, et al., 2012:495). This suggests that in the soil realm, forms of knowledge embedded in growing practices are not necessarily recognised and are instead considered as subordinate to the authority of science. Locating the microbial communities of soil in their social and political entanglements with related fields however required me to go beyond an opposition between the scientific and social domain or between scientists and growers and attempt to understand the intersection and co-production of these intricate layers. This is because, as argued by Sheila Jasanoff, the scientific and social realms are not separate but involved in a constant process of co-production, where co-production is an interpretation that overcomes the separation between nature and politics while rejecting linear accounts of social phenomena (2004).

The interrelation of epistemological locations and actors involved in the constitution of the soil microbiome field emerged as important in the layout of my methodology. In order to examine the kinds of expertise currently involved in this arena I needed a methodology that allowed me to consider the interconnections of these multiple forms of knowledge production. The main methodological question of this project therefore revolved around the most suitable approach to investigate the politics of an intersected field of knowledge and 'follow' the soil microbiome as it moves across lands, documents and laboratories. To trace the often nonlinear interconnections between sets of interests within the field and to address the question raised in this project regarding the emergence of a multifaceted object of enquiry, it was necessary to undertake ethnographic fieldwork in a variety of settings.

The awareness that entities like the soil microbiome cannot be understood with a single site approach led me towards a multi-sited methodology that assisted me in defining an object of study unable to 'be accounted for ethnographically by remaining focused on a single site of intensive investigation' (Marcus, 1995:96) and 'whose contours, sites, and relationships are not known beforehand' because 'mobile and multiply situated' (1995:102). Ethnographic approaches to the production of scientific knowledge and in particular multi-sited ethnography,

increasingly employed in science and technology studies, allow a 'juxtapositions of locations' (1995:105). This methodology addresses the need for moving beyond a single site approach to map 'the circulation of cultural meanings, objects, and identities in diffuse time-space' (Marcus, 1998:79). It is then possible to shed light on how scientists and other actors are entangled 'in culturally informed realities' and to explore and be aware of wider interconnections in the field (Lock and Nguyen, 2010:10). In this sense, a multi-sited approach is not about finding the 'relevant locations' to study such as laboratories, but about exploring spaces 'where interesting things might be going on' (Hine, 2007:661). Because the microbial object of my study is multifaceted, this methodology allowed me to be mobile and shift between sites across different realms of knowledge construction to look at the interconnected ways in which this field 'takes place'. In proposing a qualitative multi-sited ethnography that recursively explores the multiple kinds of practice, expertise and sets of interests involved in the formation of the microbial communities of soil, this thesis also addresses the broader question of the constitution of scientific knowledge in its inseparable relationship with other social practices.

Furthermore, my method was influenced by the growing significance in anthropology of a multispecies approach linked to the increased acknowledgment of the vicinity and interminglement of organisms, including microbes and plants (Kirksey and Helmreich, 2010). The central question asking 'what is anthropos becoming?' (2010:548) worked as a reminder that in the quest for an exploration of human/microbe relations across a variety of spaces, microbes are not only an object of study considered instrumental within current anthropogenic degradation, but also a living and moving agent of change and transformation for the humans who *touch* them and are affected by them.

In designing my methodology I also found particularly useful Luis Artur and Dorothea Hilhorst's multi-sited ethnography on climate-related disasters increasingly occurring in Mozambique (2012). In looking at flood response, the authors follow the dominant and contradicting claims emerging in the domains of science, management, governance and local responses. Despite their diversity, Artur and Hilhorst consider these domains to 'have a certain proximity' (2012:530). They argue that the

multiplicity of competing discourses and sites of flood responses in Mozambique are both disconnected and interconnected. Thus, they avoid oppositional dichotomies that depict certain responses as belonging to one particular group or site. Instead, Artur and Hilhorst consider disaster response as being multiply produced across distinct sites that are however 'connected through different relationships of association, constitution, interaction or reaction' (2012:530). They suggest shifting sites and perspectives as a way to understand a complex phenomenon. Similar to how they examine the concerns for floods and related responses as traversing sites, I consider the ambivalences in the interconnection of spaces where soil microbiome knowledge circulates. In doing so, I am able to appreciate the multiple complexities of this field, its contradictions and the transformations it undergoes as it crosses over knowledge domains.

Multi-sited ethnography allows me to 'follow the thing' (Marcus, 1998:91), knowledge and practice around microbial communities, but also the stories and the discords across labs, offices, growing sites, events, leaflets. While the soil microbiome exists out there, in the depth of soil and the rhizosphere, it is also a human and specifically scientific concept, an entity defined by laboratory researchers and appropriated by policy specialists and growers. It is growers', policy experts' and scientists' conceptualisation of and relation with the microbial that I am interested in examining in this research, following a knowledge that travels, circulates across sites, changes and in turn alters the people it meets, a knowledge that is translated and modified, exploited, defined and simplified.

While my methodology entails the exploration of a number of sites such as growing fields and scientific laboratories, my approach to multi-sited ethnography slightly diverges from its literal and general use as devised by Marcus (1995; 1998). The multiple 'sites' of my ethnography are understood here as epistemological spaces rather than purely geographical ones. My ethnography is multi-sited not only because it enters agricultural or scientific spaces, but because it engages with different fields where soil microbiome knowledge is produced. In their constitution of my object of research, the scientific, growing and policy domains are therefore the

epistemological ethnographic sites I explore in their multitude, diversity and role in the creation of this knowledge.

A number of writers consider multi-sited as a global methodology that is about connections and moving objects (Burawoy, et al., 2000). A move towards an attention to the soil microbiome can be identified in global socioeconomic trends in research and agricultural practice that are making the microbial communities of soil relevant. In the 20th century, societies that rely on scientific expertise started to undergo a shift towards a recognition of soil as a critical and limited resource after long term neglect (Brevik and Hartemink, 2010). This shift can be observed in a number of world-wide initiatives aimed at raising awareness on the microbiology of soil. In 2015 the International Union of Soil Sciences launched the 'Unified Microbiome Initiative' with the aim 'to understand and harness the capabilities of Earth's microbial ecosystems' (IUSS, 2015). The complexity of studying microbial ecosystems in soils was also recently highlighted by the Food and Agriculture Organization of the United Nations (FAO, 2020). However, while recognising this global trend in the emergence of the soil microbiome as important, I follow the interconnections of knowledge spaces with the awareness that there is also a singularity in the way the soil microbiome is constituted at a local level. Rather than global geographical movement, transnational connections, or the 'total world system' (Marcus, 1998:83), my multi-sited ethnography engages with the circulation and transformation of soil microbial communities across multiple sites with the conviction that there is value in looking at a singular location such as the UK in its geographical and political context.

The UK has a specificity that makes it particularly significant to study. A growing concern with the state of soil and its invisible life is increasingly addressed in UK political and regulatory arenas. In 2017 the Secretary of State for Environment, Food and Rural Affairs, Michael Gove recognised the urgency of soil degradation by stating: 'no country can withstand the loss of its soil and fertility' (Environment Agency, 2017:1). Awareness of the importance of safeguarding UK soils for agricultural and environmental purposes is leading to an increased focus on the significance of soil microbial communities. There is a recognition that 'soil microbiomes are an

important component of many processes which influence soil fertility' (Microbiology Society, 2020b:2). In the growing realm, debates on the importance of the biology of soil are reaching UK farmers' organisations such as the Agriculture and Horticulture Development Board, perceptibly involved in disseminating information around the topic (AHDB, 2019).

Beside the renaissance of soil with particular focus on its invisible life, the UK's singularity is also related to its early industrialisation driven by the colonial enterprise, with environmental repercussions such as the draining of resources in abused territories (Bonneuil and Fressoz, 2016). The UK's agricultural dependency on other countries and other soils for its food production as well as its high carbon emissions and role in climate change lead historians Christophe Bonneuil and Jean-Baptiste Fressoz to suggest the *Anglocene* as a more suitable term than the Anthropocene[5] (2016). Because of this exploitative history, the UK represents an important site to study in relation to its instrumental attitude to resources, an attitude I will show to be present also in the study of soil microbial communities. Having looked at the design and rationale for my methodology, the following section addresses the practical question of locating the interwoven sites of knowledge involved in the formation of the microbial communities of soil.

Research sites

In order to follow the soil microbial communities across authoritative forms of knowledge production as well as soil practices with an ethical sensitivity, I found useful Isabelle Stengers' concept of ecology of practices as 'a tool for thinking' that is never general but always specific and particular according to the context (2005:185). Practice for Stengers is not separable from the individuals and it is to do with an 'ecological identity and the possibilities of becoming' (2010a:48). The ecology of practices requires a 'constructivist approach that affirms the possible', it is about creating problems, 'detected at the same time as they are produced' (2010a:57). This

[5] A term referring to the current epoch, characterised by anthropogenic environmental and geological devastation and the exhaustion of natural resources (Bonneuil and Fressoz, 2016).

non-descriptive frame looks at the possibilities of practices becoming something else when interacting with different species (2010b). Stengers' constructivist approach meant that as I engaged with growers, scientists and policy experts I became part of the field and attempted to affirm the possible rather than just describe. I provide an instance of this approach in chapter five, where I consider how growers' relationship with microbes emerges in their practices aimed at soil protection and nourishment rather than in their everyday talk about them. When examining more closely their attitudes to microbes however, growers assert their interest and particular ways of engaging with them. It is precisely in the moment when I notice the emergence of this connection - growers becoming more in their interaction with microbes - and detect the problem at the same time it comes to the surface, that I affirm the possible in changing practices and relations.

Stengers suggests to look at the relationship between established scientific practices and minorities able to put a neglected issue at the forefront of the ecological debate. For Stengers, a minority is not a specific dissident group with oppositional implications, it 'is not sharing a common feature but entering into a process of connections', thus minority contains a 'togetherness' (2010b:14). The idea of minority is relevant in the practice, seen as 'an attachment to a nonhuman' that 'has the power to make practitioners think, feel, and hesitate' (2010b:15). I was particularly interested in Stengers' connection of practices with minorities and the possibility of becoming something different through the interaction with the microbial nonhuman, but I took the ecology of practices also as an invitation to think about the meeting of non credentialised forms of knowledge such as sensorial experiences practiced in growing sites and authoritative ways of knowing produced in laboratories and policy arenas.

In preparation for my fieldwork, I had preliminary, informal meetings with scientists studying the microbiome of the soil as well as of the human gut. To familiarise myself with relevant discussions and debates, but also to make contact with experts, both before and during my fieldwork I attended a variety of events, conferences, forums and workshops on soil and the microbial world. These included *Soil: Our Buried Treasure*, a showcase of soil academic research open to the public, *Wonderful*

Woodchip!, a workshop on woodchip as a growing medium aimed at growers and *Open Farm Sunday*, an annual event where farmers open their gates to the public for educational and entertainment purposes. I also became a member of the British Society of Soil Science[6] in order to be part of the conversation taking place in the field. My access to UK microbiologists and growers benefitted from my enrolment in IFSTAL[7] (Interdisciplinary Food Systems Teaching and Learning), a programme involving five UK higher education institutions, including the University of Warwick, that facilitates collaboration and networking between members, farmers and industry in the field of food systems and agriculture. Attending the first IFSTAL Summer School at the University of Reading proved useful in that alongside lectures and group-work on food and systems thinking, the activities included a visit to Tolhurst Organic, the first Stockfree Organic[8] certified farm in the UK (Grow Green, 2019; Stockfree Organic Services, 2020), whose commitment to soil and wildlife had an impact on the evolution of this project and on my own relation with food and agriculture.

My ethnographic fieldwork consisted of a six-month participant observation of a food growing cooperative, visits to five other growing sites and four research laboratories, thirty semi-structured interviews with seventeen scientists, seven growers and six policy experts, documentary analysis and photographic data of the locations explored (see Appendices C and D for a list of all my field sites and of the pseudonymised interview participants). The fieldwork started in January 2018 and ended in March 2019, although I attended microbe and soil related events for a longer period. The recursive nature of my ethnography meant that each visit, observation or interview would inform the next, enabling me to reframe focus and questions. Rather than numerical balance, what mattered in my investigation was to follow the travelling of the microbial communities across the multiple fields they traverse. The shifting of sites allowed for an appreciation of experts' understanding of their own as well as other forms of expertise involved in the field. Addressing all sites recursively rather than proceeding by categorising the scientific, policy and

[6] www.soils.org.uk
[7] www.ifstal.ac.uk
[8] Free from animal inputs (Stockfree Organic Services, 2020).

growing realm separately, was crucial in delineating the relationships that constitute this field. By moving between sites, I could better comprehend how different kinds of actors conceptualise their competence in the context of wider contemporary environmental and agricultural challenges.

The research sites and participants were mostly found through websites and profile pages of the employing organisations. A number of interviews resulted from approaching the experts at soil-related events; on some occasions sites and experts were referred to me by other interviewees. I adopted a purposive sampling technique to select scientists and policy experts 'due to the qualities the participant possesses' thus based on their field of expertise and experience (Etikan, Musa and Alkassim, 2016:2). When selecting growers however I was constrained by location and access issues related to the rural position of various growing sites. For this reason I used convenience sampling which allowed me to identify growers who were accessible to me and at the same time responded to the criteria (small scale and organic growing) needed to address the research questions delineated in chapter one.

Because of the diversity of expertise within the sample, the interview questions varied according to the respondent's competence. Semi-structured interviews enabled me to modify the questions asked in line with the participant's background and expertise and to be flexible in following hints and interesting directions raised in the course of the interview. According to the way the interview unfolded I could change the order of the questions and adapt it to follow the flow of the interview. Rather than adhering to a strict interview guide, I utilised a sheet with a few words or prompts as reminders of each question. The interviews were carried out face to face in the interviewees' office, university rooms, cafés and open fields; three interviews were performed via video call because of location issues. Interviews and informal conversations performed at growing sites, research centres and policy offices assisted me in integrating the spaces and sites explored with the ways in which those occupying these spaces describe and conceptualise the microbial world. They allowed me to listen to and capture the voices and attitudes of those involved in the workings of the microbial soil who are strongly and concretely invested in the

co-production, enactment and possible outcomes of soil microbiome research. I now consider in more detail each site explored in my ethnographic fieldwork.

To explore the minoritarian forms of knowledge construction suggested by Stengers and to consider the prospect of soil ethics that place the human within, not above, the soil field, I carried out ethnographic observation at a worker cooperative[9] that grows and sells organic produce on the outskirts of a large UK city. The cooperative was founded with the main aim of reconnecting people, land and food, involving the local community in the process of growing and thus gaining a form of autonomy. The coop promotes a number of activities such as the provision of horticulture courses and projects that involve young people and people with learning difficulties. Embracing equality in food production, the cooperative's practice suggests that strong belief in community can be politically transformative. I chose the cooperative for its strong ethics around the importance of land and community and for its philosophy that counters business-types of attitudes by practicing 'people care' and appealing to humans' playfulness while celebrating the beauty of nature. As part of my fieldwork, I volunteered at the cooperative once a week for six months from February to August 2018.

Aside from the participant observation at the cooperative, my visits to agricultural and growing spaces brought me to five further sites: a twenty-acre farm known for its ethical and environmental commitments, a growers cooperative, a city farm providing produce to local restaurants and public entertainment, an urban growing space which is part of a local cooperative development agency and a mixed dairy and crop farm hosting a university research unit. For location and accessibility reasons, these sites were all based in South East England. Apart from the university farm, the sites were either organically certified or effectively grew organic produce without the official certification. I focused on organic growing because I detected an interest in soil microbial life among growers who are required by official organic standards 'to

[9] Forms of cooperatives 'owned and run by the people who work in them' (Co-operatives UK, 2012:2).

maintain the long-term fertility and biological activity of soils' (Soil Association, 2020:8).

The engagement with these growing projects constituted the more mobile and sensorial side of my multi-sited ethnography, involving walks in the fields and relating with plants, soil and agricultural tools. Walking with farmers and growers on their land and urban growing spaces allowed me to explore their relationship with soil and to consider the practical issues and concerns they faced as small scale growers. It also meant putting into practice my invitation to sociology to engage with elements long considered confined to the natural realm and therefore outside of the disciplinary domain, such as the materiality of soil and plants. Being involved with the concreteness of the 'natural world' represented a praxis of becoming bodily engaged with soil I felt urged to experience first-hand.

Aside from the visits and informal conversations with growers, I also carried out formal interviews with seven growers and cooperative workers based at five of the sites visited. I chose the participants for their involvement in growing projects with evident environmental and ethical focus, elements I considered useful in starting a conversation around the relevance of microbial communities living in soil. Some of these were typical ethnographic interviews conducted on site with growers I had met several times at the cooperative or following farm visits, to 'gather rich, detailed data directly from participants in the social worlds under study' (Heyl, 2001:369). These interviews provided me with important material to trace the 'arrival', circulation and transformation of soil microbial knowledge in growing sites. I could reflect on the actual working of soil and the epistemological closeness and distance of food growing spaces from research sites. The integration of sites' visits with interviews was motivated by the awareness that data from ethnographic observation often originates from informal interviews performed in the field (Fontana and Frey, 1998). To follow the circulation of the microbial object, I considered important talking to the actors involved in its constitution also through formal interviews.

Alongside growing sites, I visited four laboratories connected to research centres and universities in England. These were: two laboratories located within research centres performing soil microbiome research, a relatively small 'growing room' located on

the top floor of a university building and a large state-of-the-art facility arranged on two floors, also based at a university campus. Unlike the growing room where the weather had an effect on the internal conditions, the latter facility provided the life sciences staff with a fully controlled environment where tests and experiments could be repeated over time under identical conditions. Visiting these facilities enabled me to literally enter the space of science and experience the environment where soil microbiologists work and perform their research. I could become aware of the challenges that some of these facilities entail and of the technologies that are making the expansion of this field possible.

To integrate this ethnographic data with formal records and insights on microbiologists' perspectives, I interviewed seventeen scientists at different levels of their career based at eight universities and research centres. The scientists' position ranged from early career researcher to professor and group leader. Most scientists were studying or had studied in the past, the microbial communities of soils and the field of plant-soil-microbe interaction. Two of them were crop and nutrition scientists working on pest control and agriculture and were interviewed because of their involvement in interdisciplinary projects, an element I initially considered important in understanding and tracing the relationship between different expert areas. While some of the scientists came from a microbiology background and later acquired a deeper competence on soil, for others the disciplinary trajectory had followed the opposite evolution. This was evident also from their diverse titles and specific area of expertise that was not always clear-cut.[10] The aim of the interviews was to explore how the soil microbiome emerges as an entity worthy of attention, how the different kinds of practice, expertise and sets of interests intersect and co-produce the field and the relationship scientists have with microorganisms. Interviewing soil microbiologists enabled me to examine their conceptualisation of microbes, the questions currently asked in soil microbiome research and the complex

[10] While Appendix D indicates each expert's main title, in regard to scientists allocating a specific title was particularly challenging because of their numerous skills and interdisciplinary competencies. Despite my attempt to provide an accurate description, their expertise may result reduced to a label that does not reflect this complexity.

interconnections between recognised expert knowledge and the less authoritative competencies found at the growing sites.

My multi-sited ethnography also included the exploration of a variety of texts and materials with particular focus on UK policy documents. I had relatively unproblematic access to diverse documentation regarding the soil microbial communities: scientific papers and journals, leaflets for farmers, newspaper articles, farmers' forums, policy documents, soil science and microbiology textbooks, growers' bulletins and journals, research centres' publications, departmental brochures for students, societies' reports and briefings. To follow more effectively the constitution of microbial communities of soil in policy, I interviewed six policy experts and advisors affiliated with as many diverse institutions and organisations. One of the policy specialists was based at a US institution and was interviewed for her expertise in global trends in food and agriculture, an element I considered relevant in the acknowledgement of the global character of food systems (Wilk, 2006). Some of the experts were actively involved in microbiological work, others in the promotion of soil health, in food policy or in research strategy. Given the experts had different areas of competence, each interview took a different focus ranging from the policy dimension of soil science and food systems to broader concerns and challenges of the practice of public policy. This different level of discussion enabled me to contextualise the regulatory aspect of the soil microbiome within a wider debate around the translation of scientific knowledge and the complicated relationship between publics and expertise.

When possible and when permission was granted, I documented my ethnographic fieldwork through photographic images. The visual data, consisting of almost 400 photos, documented growing sites, labs and public events. When photographing, I did not consider images as a straightforward representation of reality, but a record of what I intended to make visible (Pink, 2007). In this sense, the photos did not simply record what was there but what was relevant *for me*, the person holding the camera and choosing what to include and exclude from the frame. In this sense, photographs are both objective and subjective data, 'a record of that to which attention has been paid' (Grady, 2004:21). Howard Becker compares a camera with

a typewriter in that its possible uses are diverse, thus dispelling the myth that cameras simply represent what is there and hence problematising the truth of a photograph (Becker, 1974). While I am aware that the reality I photographed was only one of the many that could have been captured, that reality was not a mere fabrication but it existed at least for the moment needed to take the image.

Ethnographic photographs often are not bounded to belong to the specific category of fieldwork only, but they merge into the lives of the researcher, as Sarah Pink suggests (2007). In my case, a number of events I attended and photographed had this element of merging leisure and personal interest with the duty to be present in case something ethnographically relevant happened. Many of the images taken at microbes and soil events hold this dual presence and ambivalent role. Furthermore, because of the invisibility of the microorganisms living in soil, taking photos in laboratories, agricultural fields and at public events facilitated the conceptualisation of my own relationship with microorganisms. I used objects such as pots, plants, soil and lab equipment as proxies to think about microbes beyond the need to see them. Visual data in this realm ultimately taught me to imagine microbes despite their invisibility. This visual data also assisted me in focusing on particular aspects as well as elements that emerged as 'out of place', such as the stereo featured at the state-of-the-art facility for plant growth, or a bath converted to a pond at a city growing space (Figures 3 and 4). I considered these objects as revealing of the materiality of human presence with its idiosyncrasies and concrete needs. This visual data also acted as a reminder that the practice of science is interwoven with routine, daily repetition and often basic tasks. In this sense, photographs had the role to make connections visible. By choosing to avoid photographing individuals, a decision primarily dictated by ethical issues around identification, I attempted to find meaning in objects, tools and landscapes. These 'things' had to talk for human practices, attitudes and conceptualisations. They also allowed me to document the travels of an invisible object across a multitude of spaces.

Figure 3: Lab room with stereo, showing unexpected scientists' requirements

Figure 4: 'Pond' at a city growing site

Data analysis

Making sense of complex phenomena is about accepting the complexity rather than trying to simplify and clarify the chaos (Law, 2004). John Law suggests to move beyond the need for certainty by employing ways of understanding intricate realities and messiness such as embodied forms of knowing. For Law, rather than a technical exercise, method is performative and creative in the sense that it contributes to create realities with political implications. In the interpretation of my diverse data, I took these arguments as a reminder that certain objects cannot be easily described and there is no 'real' reality to discover. An object is enacted, made to perform and constructed 'rather than discovered, analyzed or animated' (M'charek, 2005:15). My

analysis question was thus aimed at delineating this complicated story by allowing the interconnections to emerge and acknowledging that the soil microbiome is an object in the making. I therefore attempted to make sense of the absence and invisibility of the soil microbial world by allowing untidy entanglements and the contested nature of the field in its unresolvable complexity to emerge and exist, avoiding simplification and the search for a linear story. While making the neglected object of my study visible was not a straightforward process, the complexity of thinking with absence meant acknowledging and embracing the messiness of reality thus stretching speculative reflections and making them count as affirmative possibilities.

I started analysing the data in May 2018, three months into the ethnographic observation at the cooperative and having carried out ten interviews. The data analysis process reflected the conception of my research sites as intermingled and connected. In this sense, analysing the data as it traversed sites assisted me in holding diverse spheres of knowledge as part of an intricate field rather than attempting to isolate each singular site. The visual data assisted me in this process of thinking across sites. Tracing the interwoven links within the field was also facilitated by how frequently participants mentioned the same event, paper or project. Reading scientific literature on the soil microbiome throughout the research process, with papers often referred to me by interviewees, also assisted me in identifying possible interpretation routes.

I approached my data through thematic analysis. Themes are patterns identifiable in the data, a way of seeing that precedes interpretation (Boyatzis, 1998). The systemic analysis of themes enables the appreciation of 'observations about people, events, situations, and organizations' (1998:5), making it the most suitable approach to analyse the interconnected fields and sites involved in the constitution of the soil microbiome. Virginia Braun and Victoria Clarke stress the flexibility of thematic analysis as 'a method in its own right' (2016:78). They argue against a passive account of analysis where the researcher merely speaks for a data that is already there only waiting to be seen (2016). Instead, thematic analysis is useful in responding to research decisions and questions. Furthermore, the presence or relevance of a

particular theme is not necessarily related to its pervasiveness in the data set but instead to 'whether it captures something important in relation to the overall research question' (2016:82). In my research, an instance of a subtheme that was less prevalent than others is discussed in the following chapter as part of the broader theme around the future orientation of soil microbiome knowledge. The subtheme centres on the urgency to re-establish a relationship with soil and food, proposed by some of my participants. While this need was highlighted by experts across different fields, its relevance for this study is not determined by the prevalence in the data set but by the ways in which it responds to my research question around the technological drive of soil microbiome research. In its standing against a pervasive technofix attitude of the field, this subtheme captures the disputed nature of innovation-based and technology driven science and is therefore as relevant as other elements that may be more prevalent in the data set.

Given the multifaceted quality of my object of study, I was interested in looking at how broad themes circulated and changed across fields. Considering how the material and data traversed sites and categories proved to be more productive in understanding the multiple and ambivalent character of soil microbiome knowledge than finding systemic categories and separating each domain explored. The recursive nature of my multi-sited interactions facilitated the generation of initial patterns that then became more defined as the data collection proceeded. Early smaller themes emerged and were later subsumed into large ones; smaller categories were slowly assimilated into larger categories. At this stage I interrogated my data with questions such as '"what is the overall story the different themes reveal about the topic?"', thus considering a wider narrative of intersections beyond the single patterns identified (Braun and Clarke, 2006:94). Ceryn Evans' study on civic participation in volunteer work also assisted me in questioning the mere semantic meaning of the data and ask instead 'what does my data actually mean?', thus to search for a more latent meaning and the underlying assumptions of what was said (2018:4). Her work was also useful in allowing for a shift in my tendency to consider representativeness and thematic relevance only in quantitative terms dependent on the number of participants who mentioned a particular element. I could then include aspects I considered relevant

because they spoke and related to the enquiries driving my research, even when they were not quantitatively mentioned by 'many' but only the consideration of a 'few'. The immersive nature of the pattern recognition stage meant that an initial interpretation of the themes preceded the involvement of theoretical discussions or explanation. Only in the later stages of writing did theory find its way back to 'illuminate' the data.

The most mobile side of my ethnography enabled me to stay grounded in the experiential, embodied and sensorial nature of growing and laboratory practices. When analysing the data, my walks along fields exploring crops and agricultural tools were invaluable in relating to the livelihoods of those involved. They also illustrated the distant nature of policy recommendations and scientific debates on the microbial world, discussions that appeared as starkly detached, removed and somehow irrelevant when confronted with the materiality of soil. Accessing the scientific space on the other hand assisted me in connecting scientists' definitions and descriptions provided in the interview settings to the routine and practical nature of their activities. The lab visits also allowed me to immerse and identify myself with the concrete reality experienced by scientists, made of sophisticated technologies and machinery. Analysing the data, it was then easier for me to understand that certain attitudes that at first appeared as showing a lack of reflexivity in scientists' accounts, were grounded in their training and daily practice. Without the more ethnographic side of the fieldwork I would not have been able, in the analysis stage, to trace these connections and ambivalences across spaces.

With particular reference to the interview data, all the interviews were audio recorded and fully transcribed, including utterances. The total interview recordings amounted to just under twenty hours, with a full transcript of over 187,000 words. Transcribing the interview recordings verbatim as I went along meant that topics and themes of interest were identifiable throughout the process and could inform the ongoing fieldwork, rather than being left to the conclusion of the data collection. I considered the text through an immersive approach where I became deeply involved in the interview transcripts, reading them multiple times. This iterative and slow process assisted me in the recognition of initial patterns and it included searching for

key themes repeatedly in the data set. Because scientific language has an impact on the kind of evidence researched, I found particularly fruitful to consider the language used as well as the language avoided and omitted by scientists and other participants. Following Evelyn Fox Keller, I considered the words employed in the scientific realm as able to bring 'scientific energies and attention in particular directions' (1995:21). The experts' metaphors often proved crucial in my understanding of the most delicate and sensitive areas scientists carefully handle in their work.

I assigned pseudonyms to all participants and throughout the thesis I refer to their main expertise as either 'scientist', 'policy expert' or 'grower' (and one 'horticulture teacher') while providing further background when relevant. This is because, despite the different roles experts performed even within the same area of competence, the definition clarifies that I approached each participant as a specialist of a particular sector and therefore I consider the significance of their contribution to this thesis in reference to the three broad communities of practice I explore. I edited participants' quotes, omitting for readability repetitions that do not add meaning to the quote or interjections such as 'um', 'you know', 'kind of', 'like'. I left these untouched when relevant or telling of a particular meaning. Inevitably, some of the interviews turned out to be more useful than others and therefore are used throughout the thesis to a greater extent.

In conjunction with the analysis of the interviews I also examined two policy reports published in recent years in the UK, chosen because they refer to the microorganisms living in soil: the 'Unlocking the microbiome' report published by the Microbiology Society (2017) and the 'Soil Health' enquiry published by the House of Commons Environmental Audit Committee (2016). In analysing these policy documents I followed Lindsay Prior's argument on the performative nature of texts, thus examining the function rather than mere content of the documents (2008). I diverge from Prior in his critique of thematic analysis for its focus on content, the emphasis on text as provider of evidence and facts and the lack of attention to the function of the document itself. I believe instead that exploring the emergence of themes enabled me to reconcile the plurality of spaces examined in this multi-sited

ethnography while still considering the function that texts perform. The analysis of policy documents, undertaken in chapter four, allowed me to address the ways in which the microbial communities of soil as an object of enquiry emerge, are enacted and translated into policy recommendations.

In the analysis process, the visual data assisted me to think 'transversally'. I was able to link practices or approaches to microbial life operating at different sites through the use of images capturing the same objects such as compost making tools and pots across varied locations, as I show in chapter four and five. This visual linking of sites enabled me to trace a dialogue between different spaces of knowledge production such as the lab and the agricultural field. On a more general level, the photographic material turned out to be useful field notes and documents of what I saw, visual reminders of places, visits and experiences that I could not have documented with written notes. This allowed for details of informal conversations and events occurred on my agricultural or lab visits to inform my analysis and not to be lost. An example of this is found in chapter five, when I recall a non-recorded conversation I had during a farm visit with grower Neil on an earthworm emerging from the compost of a young courgette plant. Without the visual reminder of the event, that exchange could have been forgotten and lost.

If sociologists who are to analyse photography need to 'acquire new habits of seeing' (Becker, 1974:7), by observing the details of photos that appeared as particularly useful in interpreting the data, I became more sensitive to the functions of the elements I decided to include and exclude from the shot. Thus, alongside seeing them as ethnographic field notes or mere illustrations of a point or an argument, I attempted to consider photographs as also data and information. In this way, the images added complexity to my interpretation, reminding me that plants do not only grow in fields but also in labs and that microscopes can be found in growing sites as well as in research centres. In this sense, they provided an undeniable visual evidence of those out of place objects.

While analysing the data, my research questions gradually evolved, acquiring both clarity and complexity in a recursive dynamic where questions both drove the interpretation and were in turn transformed by the process. My central questions

focused on the coming to matter of the microbiome as a co-produced scientific and social entity and explored the sociological contribution of an engagement with the soil and its microbes for a repositioning of the human in the soil field as one of its members. Over time the questions became more transformative and aspiring to imaginaries not previously explored, interrogating possibilities for novel becomings in human/microbe relations towards a conception of microbes as able to *move* humans and affect the production of scientific knowledge, enquiries I consider especially in chapter six.

With the research questions evolving, also themes and elements I initially considered important revealed themselves to be less present or relevant than expected. In particular, an early focus on interdisciplinarity turned out to be not as interesting in the understanding of the field. Talking with experts about their experience and appreciation of interdisciplinary work, their considerations ended up confirming much of what is known to sociologists interested in the area, namely the power asymmetry often characterising collaborative projects, where the social sciences receive lower epistemological consideration compared to the life sciences, resulting in their devaluation (Callard and Fitzgerald, 2015; Lyle, 2017). Because of this, the question of interdisciplinarity evolved into a discussion around the concept of translation and circulation of soil microbiome knowledge, an element that runs through the thesis and is explored more specifically in chapter five.

The recursive nature of my research also allowed contradictory attitudes both within the same expertise and between different areas of competence to surface. Alongside the dialogues and commonalities traversing spaces of knowledge, a number of instances emerged where one site gave rise to a different interpretation compared to another site. One of these, analysed in chapter four, concerned the ways in which microbial technofixes are embraced across places and expertise, indicating diverse attitudes towards technology and solutions to sustainable food production proposed by different participants. While small scale growers show a certain resistance to high tech and microbial technologies, in policy and science the support for agricultural innovations is more widespread, nuanced and complex in a coexisting rejection and appreciation of these solutions. Another recursive illustration presented itself in the

confrontational discussion between policy advisors eager to translate scientific knowledge into policy recommendations and soil microbiologists sceptical of the overt simplification of their complex object of study, an element I explore in chapter five. These instances demonstrate as well as assert the usefulness of a recursive approach that emphasises, rather than simplifies, the complexity of a moving object.

Ethical considerations

This project complies with the recommendations of best practice indicated by the University of Warwick Humanities and Social Sciences Research Ethics Committee (University of Warwick, 2020).[11] While this thesis deals with expert knowledge, ethical guidelines here are not understood as merely aimed at informing participants of the scope of the study, obtaining their consent forms and giving them the right to withdraw. They also concern more subtle situations where for instance only some of those present in a particular site could have been aware of my ongoing research. In these cases, I pursued the proactive attitude to assess each occurrence individually and make a decision according to the circumstances, where respect and protection of the participants constituted the primary factors. This meant deciding not to refer to particular events or circumstance not covered by a consent agreement. I also committed to provide a non-technical summary of the research findings to those who expressed an interest in its progress and outcomes. As for my involvement with the food growing cooperative, when I was invited to give a talk about my research to members and volunteers, I was able to share more broadly the research's aims, rationale and initial findings. This enabled me to be more public and transparent in my motives.

In terms of ensuring full participants' anonymity, this can be a challenging endeavour in that details and identifying expressions can be revealed in interviews' quotes. This aspect was particularly evident in regard to specialists in policy and science. The often 'vivid and detailed' descriptions (Mertens, 2017:512) provided by participants can

[11] The information sheet provided to the interviewees and the consent form are attached as Appendices A and B.

clearly expose them to identification despite the precautions taken to minimise their recognisability. I therefore addressed the matter in a number of ways, including the omission of details that I regarded susceptible to expose participants to identification, the use of pseudonyms in all interview-related material apart from the consent form and the storage of the interview material on password-protected hardware. I hold written permission to use all photographs of non-public settings published in the thesis and none of these include individuals or clearly identifying elements.

Although the consent form only covered participants' anonymity and not their institutions, after long deliberation with myself I decided against mentioning the universities, research centres, farms and cooperatives involved in this study. I am aware that some of these official institutions may be considered influential and authoritative places of knowledge formation. A case against anonymity could be made because of their public nature. However I do not necessarily believe that those working in them hold such strong powers. Even when engaging with groups of experts or 'elite' such as policy specialists who are generally excluded from the notion of vulnerability, the idea that power relations are homogeneous, unilateral and constant is problematic (Lancaster, 2017). Instead, their sensitivity and vulnerability in terms of identification was apparent to me throughout both the fieldwork and analysis stages.

Soil microbiology in the UK is not an immense world, at least thus far, and the cooperative scene is even smaller. In this relatively circumscribed field, I soon discovered that many of the growers, scientists and policy officers knew and worked with each other. This was the case not only within their main expert area, with growers having met or heard of each other, but also across different sets of competence, with some policy experts and soil microbiologists collaborating on varied projects. Once, having kindly been sent an internal rota of scientists taking part in a public event, I could recognise a number of researchers I had already interviewed. Furthermore, some of the discussions with the experts became intensely political and they did so because protected by an anonymity agreement. Given the debated nature of the field as well as the collaborations, acquaintanceships

and interpersonal relationships across sites, I considered the use of pseudonyms not sufficient to ensure anonymity. I therefore decided against a disclosure of labs, farms, universities and research centres explored in the thesis, only providing a list of public events I attended (included in Appendix C). This omission entailed the adverse effect of preventing me from openly recognising those who generously shared their time and knowledge for the sake of this research.

Positionality

The investigation into the practice of soil microbiology proposed here cannot overlook the researcher's or the participants' positionality. As George Marcus suggests, in multi-sited ethnography the researcher continuously changes her position and identification according to the sites explored (1995). In this sense, the identification with a particular participant also entails the participation of the ethnographer in their space and her positioning 'within the terrain' rather than above (1995:112). Multi-sited ethnography does not involve a straightforward identification but mobility and shifting. Positionality thus implies a changing identity of the ethnographer who becomes an activist in the sense of holding a commitment while shifting persona according to the space examined. It is this positionality that constitutes for Marcus a form of activism not related to political affiliation but specific to multi-sited research in a continuous renegotiation of identity across the diverse sites, identities that then affect other identities.

I saw this interchangeability of roles unfolding on a number of occasions throughout my fieldwork. In my experience as a multi-sited ethnographer, I recursively shifted identity between volunteer grower, interviewer, farm visitor, scientist, non-expert and member of the public. Within the same institution where I carried out five interviews, I was an intimidating presence in one case and a student deserving a lecture in another. In other settings, I was praised by a professor for working on a project that 'does engage with community, it does link out' (Andrew, policy expert) and scolded by a young grower for becoming too political. The scientists I engaged with, explained their specialist area without arrogance and often excused themselves for the jargon when suspecting my lack of knowledge or understanding of a particular

process. Others considered me a fellow scientist. I accepted the sometimes unpleasant implications of these recursive dynamics in the same way I accept the nature of interrelations and constantly changing power imbalances. Engaging with the multiple sites and expertise involved in this field, I attempted to allow the curiosity for how people see the world guide me to join them in their reasoning and competing arguments even when these were opposed to mine and to each other. I followed Annika Lillrank in performing active listening and keeping my positions and ideas aside while engaging with those of the participants (2012). Thus, I dealt with the antagonisms and diverse positionings of others by attempting to understand their circumstances and politics. The contested nature of this field means that controversies feature abundantly in the following chapters.

While on farm and lab visits or in interview settings my position as a researcher was relatively straightforward and did not require constant renegotiation, my presence at the cooperative posed more ethical questions. In my six months at the worker cooperative, holding the double role of volunteer and researcher I often felt in a precarious balance between being considered with curiosity, waved as a symbol of the site's diversity credentials and regarded as a privileged participant. In that setting I was what Raymond Gold classifies as a 'participant-as-observer' (1958:220) in that I was part of the volunteer group and my role as a researcher was generally known, although the site had a continuous arrival of new volunteers which makes this sort of categorisation not so clear-cut. The regular interaction with cooperative members and volunteers made it possible to explain my double role as a researcher/volunteer, but this disclosure was not always practical or pertinent, especially when engaging in superficial and brief exchanges. Another element that complicated the ethical obligation to remind people of my position was the inevitably immersive nature of volunteer work. Having joined the volunteer cohort after attending an induction like every other volunteer meant that I would perform my daily work without continuously ruminating on my research purposes. On my weekly involvement with the cooperative it was unsurprisingly straightforward to see myself as a volunteer in all respects. This role was reinforced by my interest in learning about organic food growing. Thus, when at the cooperative, I *was* a volunteer.

In the interview setting, I was aware that power relations are fluid and can change during the interview itself and the interviewer's dominant position should not be taken for granted (Lillrank, 2012). Not only the participants' expertise but also my own multiple identities and social roles in the present political context had a part in this possible overturning of power. Power relations were not always in my favour, because of the experts' position as often established academics or policy advisors. Some of the experts were also clearly accustomed to being interviewed. The ease with which they explained their area of competence and at times anticipated questions and provided appropriate answers unsettled a static understanding of the interviewer's domination, power and control. However, drawing on Steinar Kvale's emphasis on the manipulative potentials of interviews, not for a moment did I consider my relationship with the interviewees as free from asymmetrical power relations (2006). Given the power imbalance, I considered this method as 'a conversation with a purpose' (2006:483). Thus, I made sure that when a formal interview was preceded or followed by more informal interactions, the interview still maintained a formal dimension and was never masked as a fluid interplay. When I sensed my position as becoming particularly dominant, I modified my questions and behaviour, simplifying or avoiding threatening queries in some cases or changing the subject in others.

Certain elements related to the interview settings may have also impacted the formality of the interviews. Consider Figure 5, showing the corner of a wooden table under a tree, the site where I carried out two interviews at the cooperative I observed. Compared to the formality of other interview settings such as an office, it is possible that the relaxing scenery may have influenced the interviewees in their responses. In the midst of the second interview performed, the interviewee and I had to move elsewhere because of the noise of a tractor. We ended up at the margin of a field, sitting on the grass and surrounded by trees and birds. Despite still formally recording the interview, these calm surroundings may have had a repercussion on how the interviewee felt about the exchange and therefore in the responses provided. The relaxing atmosphere of the fields may have had an impact on the perceived informality of the interview, with consequences on what was said. It is of

course possible that the cooperative member was perfectly used to the surroundings associated to the workplace and it was me who was affected in the questions asked. Other two occasions where I interviewed a scientist and a policy expert in a café may have had a similar implication in the perceived lack of formality of the interaction. The three interviews performed via video call, on the other hand, may have resulted in a more distant interaction, reflecting the remote modality of communication.

Figure 5: Interview site at food growing cooperative

As for my position and its role in the analysis process, it was not always straightforward to avoid a form of favouritism towards people and places I considered particularly interesting and valuable. Because of my situated stance on microbial as well as environmental issues, the analysis question often revolved around reading the data more critically when related to particular growers and scientists that appeared in my view as deeply engaged with the microbial world and its transformative possibilities. Similarly, I was particularly careful in noticing my scepticism towards more anthropocentric accounts of soil and microbes. In this sense, the recursive nature of my research continued to be at play in the interpretation stage, with varying degree of shifting persona and renegotiations of identities according to the site analysed. Furthermore, because 'the act of interpretation always involves a degree of appropriation' (Willig, 2017:141), I was aware that even a strong confidence on the meaning people assign to their words and explanations may still be simply reflecting my own worldview and be more revealing of my interpretation than of the participants'. This led me to a cautious

rather than over-assertive attitude when assigning meaning to quotes and other fieldwork data.

In undertaking this multi-sited ethnography, I also acknowledge that I was not simply describing but I was creating a problem. Amade M'charek argues that methods are interventions, actual parts of the process of construction of an object rather than a toolbox that allows the revelation of reality (2005). In this sense, a method does not merely create a particular version of an object, but it constructs the object itself, an object that did not previously exist. This is of course not only the case for scientific practice, but also for those who study this practice. By entering the soil microbiome field, I did not observe a reality that remained untouched by my presence but I became part of a process that was an intervention itself and that co-created that reality. When I asked the participants to think from a standpoint outside of their ontological boundaries, rather than uncovering their subjective experience, I asked them to become something else and create a new version of reality that was not there before. By talking to scientists and walking with growers, I entered the soil microbiome domain and contributed to making it a sociological interest thus asserting rather than merely reporting its relevance in the present time. It is in this sense that a methodology 'intervenes' in the field and creates new realities.

The coming to visibility of soil has been a slow process of mattering also for me. My interest in this realm originated in the microbial world and only slowly found its way underground. It turns out I have my own ethics of soil and a personal investment in the field. I sow seeds, I grow plants. My position on land and food affects the questions I ask and ultimately the construction of the object I set out to examine in the chapters to come. Rather than leading sociological research into a relativism oblivion, with this acknowledgement I attempt to provide 'the view from a body' rather than 'the view from above, from nowhere' (Haraway, 1988:589), a situated touch of soil that is partial, limited, local and therefore accountable.

Conclusion

In this chapter I have addressed the methodological aspects of the research and the rationale for my approach. Because the soil microbiome intersects with different sets of interests and expertise in the UK context, a multi-sited ethnography was the most appropriate approach to understand these layers of interrelations. Multi-sited ethnography allowed me to construct my object of study as multifaceted and nonlinear and to explore a number of different sites of knowledge production, thus facilitating an appreciation of this intricate field in its diverse perspectives and complexities. The ethnographic fieldwork led me to farms, labs and events; it included six months of participant observation at a food growing cooperative and the analysis of policy documents. It also involved thirty interviews with experts distributed across the realms of science, policy and growing and the collection of visual data.

The interpretation of the data reflected the multi-sited nature of the field and the interrelation of spheres involved. Having employed thematic analysis, the themes emerged were approached across sites thus always emphasising the complex nature of the microbial entity as it becomes important beyond the scientific scene. In this sense, the main and continuous effort of the analysis process was to resist the temptation for categorisation, simplification and linearity, instead allowing for the complexity and diversity of soil microbiome knowledge to emerge. It was often necessary to re-assert the significance of entering and exiting the different spaces where important relations were happening and avoid the search for a harmonic balance across sites or a linear story where the field of practice is considered determinant of the participants' standpoint.

This methodology allowed me to address the research questions outlined in chapter one (section two): how is the soil microbiome constituted across knowledge spaces? How do different practices and expertise co-produce the soil microbiome as an entity worthy of attention? In what ways does the soil microbiome circulate across fields, traverse knowledge spaces and affect the sites it enters? How is this knowledge transformed by the different practices involved in its constitution? How do microbes become seen as technologies? Are there possibilities for novel and transformative

becomings in human/microbe associations, beyond technoscience? What kind of relations with the microbial are possible? These are the enquiries that inform and drive the unfolding of my investigation in the chapters to come.

The chapter has also addressed the nuanced nature of consent and the ethical decisions made towards ensuring the anonymity of participants, where a highly political, contested and circumscribed field drove my decision to omit institutions as well as people's names. While official sites of knowledge may be considered powerful enough to withstand scrutiny and even deserve critical judgement, I took the stance to refrain from an exercise in disclosure and exposure that could result detrimental to the study's participants. Finally, I have discussed my own positionality and sets of interests within the soil field, acknowledging their influence in both the development and the outcome of the research. In this sense, following the circulation of soil microbiome knowledge entailed not only practical but also intellectual mobility and flexibility. My situated self became involved in ambivalent modes of identification with the most diverse participants. It was this shifting in 'participation' that kept my position grounded in the terrain rather than above the field. While these changing power relations were at times unsettling, I ultimately learnt to adapt my behaviour to the interplay of authority unfolding in the diverse settings explored in this research.

In describing my methodological approach, this chapter has also more precisely defined my object of study. The microbial communities of soil, or soil microbiome, are living organisms invisible to the naked eye. The increasing attention this neglected underground existence is receiving in recent times is interrelated with a number of fields of practice with different sets of interests and priorities. Because of its ability to associate with plants used for human consumptions, this life form ceases at times to be considered as living, to become a conceptual knowledge and a scientific practice. As my aim with this research is to move beyond an anthropocentric understanding of life and to propose a sociology that widens its space of interest to include life forms such as plants and microbes, it is necessary to examine and scrutinise the constitution of soil microbiome knowledge. Only by tracing the ways in which this knowledge circulates, is transformed and simplified,

how it is modified and appropriated across different domains, it is possible to re-establish microbial communities as significant in and for themselves, lives holding intrinsic value. In the following chapters I will show how travelling with this knowledge allowed me to discern that soil microbial communities are not only affected by human investigators, regulators and farmers, but in turn are able to influence, alter and move the people they touch.

Chapter 4. A story of tomorrow

Introduction

This chapter explores the ways in which the communities of microorganisms living in soil have become entangled with ideas and narratives around different versions of the future. In science and policy, they surface as tied to a sustainable agriculture agenda that promotes an increase in food production sensitive to the environment. While much of the composition and functionality of the microbial communities is still unknown, current scientific research in the field shows a consensus around an instrumental approach focused on the possibility to employ these organisms in agricultural interventions and applications aimed at the improvement of soil fertility, pest control and plant growth. Soil microbiology is thus increasingly concentrating its efforts in understanding microbial interactions with crops in order to intervene and exploit the solutions that their manipulation can offer. This approach is shared in policy debates focused on the need to harness microbial communities in order to address sustainability concerns. As I will show in this chapter, the proposal of technological solutions for soil fertility is inevitably related to a promissory agenda and an anthropocentric understanding of microbial life useful for human and economic benefits. In the context of this drive towards increasing food production, the field is entangled with the assumption that future innovations such as microbial products and the engineering of symbioses between plants and microbes will resolve urgent agricultural and environmental issues around soil depletion while ensuring the food supply.

On the other hand, the consensus around a utilitarian approach oriented to future applications for the achievement of sustainable agriculture coexists with various degrees of criticism and radical stances against an extreme use of technological interventions of various kinds. These critical positions on the accepted level of manipulation of the microbiome are combined with an uneasiness around intensive agriculture and farming methods that scientists, growers and policy experts see as detrimental to the soil and the environment. Technological scrutiny is also negotiated against a perceived separation currently in place between people and soil, with an

implicit ideal conception of nature that the participants seem to consider under attack from the very technological approach this field entails. The critical attitude depicting technology as simplistic and dissonant with nature, proposes a reconnection with the land and a slower approach to food production that can provide long term environmental and agricultural solutions, possibly making technology redundant. These ambivalent relations and approaches to technology show how the soil microbiome field is entangled with varying and nonlinear ideals of pace of change that involve different versions of the future.

Promising futures

With increasing concerns around climate and environmental breakdown and the recognised need to shift agricultural practices towards sustainability for the future of soils, discourses around technological solutions permeate science, policy and funding requirements for scientific research. In this section I consider the constitution of soil microbes as technologies aimed at the achievement of the sustainability agenda. Approaching the science of the soil microbiome as a process of intervention that is political and situated, I explore its entanglement with futuristic tendencies focused on innovation and technology and how microbial life is enacted and made to perform within the context of its instrumental exploitation.

The term technology is employed across the soil microbiome field with a variety of connotations and implications. While as noted by Amade M'charek, the question of what counts as technology has already been widely raised (2005), I now briefly address these different nuances because of the many ways in which the term is adopted by the experts involved in this study. Exploring this variation of meaning is also relevant in understanding the discordant elements of the field. One of the ways of thinking about technology is suggested to me by Peter, a cooperative grower who considers its meanings as comprising 'from the trowel to the genetic sequence' (Peter, grower). For Peter, technology includes tractors and fertilisers but 'it's also a philosophical matter' in that it is implicated in the making of boundaries between humans and land. Thus, while considering technology in the etymological meaning of craft, Peter also regards technologies as more broadly the tools that shape and

change our relationship with the environment. This is where the future-oriented meaning of technology as high tech and technoscience takes on the negative implication of affecting the connection with the land by creating a distance mediated by intervention, an issue I explore further in the final section of the chapter.

Figure 6: Farm tools

The meaning I particularly focus on in this section has a rather optimistic connotation associated with the promise of innovative solutions to food production through microbial manipulations. Discussing an object of study such as a DNA fragment, M'charek asks: 'What does it take to make a "biological" object into a technology?' (2005:151). In this field, the microbial communities of soil become a technology through the focus on their 'capabilities' and 'functions'. By performing activities like fixing atmospheric nitrogen and delivering it to the plant, microbes are seen as suitable for a manipulation that renders them promising technological tools. It is in this way that a high tech approach makes microbial life itself a technology, in a transformation operated in the lab.

Promissory technology is decidedly present in modern technoscientific discourses and practices connected with expectations for future solutions, innovations and the vision of novel interventions (Borup, et al., 2006). Technological expectations can be seen as 'wishful enactments of a desired future' (2006:286). Promissory technoscience and the politics of intervention emerge clearly in instances such as the 'extraction rights' of oil multinationals (Stengers, 2015:7). While considering greener policy on global emissions, the technological fix at play still ensures the fundamental

‘right to extract and therefore to burn up all the petrol and gas to which we can have access’ (Stengers, 2015:7). Stengers argues that geoengineering[12] is an example of a proposed ‘solution’ that allows business as usual because arguments against market driven profit are charged as unrealistic (2015). For Bonneuil and Fressoz, the current narrative around the Anthropocene also ignores the multiple answers proposed by civil society and activists, confiding in scientists to find market based solutions to the large scale geological breakdown caused by the human species (2016). In this way, the destruction provoked by technoscientific innovations is seen as only solvable by new interventions.

This orientation to the future, tied to the promise of meeting the sustainability agenda, is evident in soil microbiologists’ accounts on the possibilities of exploiting microbial life. Their narrative shows feelings of anticipation for the potential of discovery around a new agro-ecological future where soil microbes play the kind of critical role that Granjou and Phillips note when interviewing French soil microbiologists (2018). The promissory agenda entangled with the use of microbial organisms in agriculture demonstrates a shift soil microbes are undergoing, where they are now acknowledged for their assistance, rather than threat, to human life, thus becoming ‘agricultural labourers’ that can provide agricultural services (2018:395). Among UK soil microbiologists, the optimism permeating this field also emerges in the awareness that microbial technologies are currently not proving highly effective, as reported by a number of scientists interviewed, therefore the hope is projected to a future where interventions *will* be successful.

Joseph, a bioinformatician based at a prominent university, represents an instance of high technological conviction around the exploitation of the soil microbiome. For Joseph, microbial communities are ‘untapped resources’ that once better understood can be used in agriculture ‘for us, for humans ... for our purposes one day’ so to ‘design our own systems in the future’ through ‘synthetic symbiosis, or parasymbiosis’ (Joseph, scientist). In terms of the ability of bacteria to fix nitrogen, Joseph considers that ‘some bacteria are doing that for free in the soil’ thus looking

[12] Large-scale technologies aimed at reducing the effects of climate change, including the removal of carbon dioxide from the atmosphere (Harvard's Solar Geoengineering Research Program, 2020).

at microbes for their usefulness as ecosystem services and for offering a convenient economic transaction to exploit. In his future-oriented narrative full of hope for the promise of artificially engineered symbioses, Joseph reflects on how these are limited to certain plant varieties who 'have the ability to talk to' the nitrogen fixing bacteria (Joseph, scientist). He is hopeful that once these interactions are better understood, it will be possible to intervene with some engineering to force the beneficial symbiosis onto other plants. This is because he believes that, from an evolutionary point of view, the symbiosis must involve some costs to the plant and this means that not all plants can engage in this association with microbes. For Joseph, these costs can be overcome, once again 'with a bit of engineering' (Joseph, scientist). Joseph therefore believes that with the assistance of technology, plants that for millions of years have not interacted with particular bacteria, will be able to engage in new relationships. Inevitably, the narrative becomes one of manipulation of natural processes oriented to future applications and later 'improvements'.

Coexisting with an endorsement of microbial technologies and the manipulation of microbial life, Joseph also proposes an equivocal position in terms of other technological manifestations he refers to ironically, such as 'tractors that can fire some lasers on some weeds and space wars' and what he defines 'advanced technology' and 'cyber technologies' currently being introduced in agriculture. Joseph is sceptical of these interventions and he seems to regard them as unrealistic and not necessary, thus 'we're not connected with that work yet or ever' (Joseph, scientist). While Joseph views soil microbiology as a scientific adventure of the future, he also carefully assesses and distinguishes the usefulness of different technological innovations.

One of the technological manifestations proposed by the soil microbiome field is bioinoculants, also referred to as inoculants. Bioinoculants are microbial products, a 'formulation of advantageous microorganisms that when added to the soil directly or indirectly improves the nutrient availability to the host plants and promotes plant growth' (Tallapragada and Seshagiri, 2017:475). The conversations I had with soil microbiologists show ambivalent attitudes where bioinoculants are considered a future potential but for the moment they are seen as too generic and not universally

effective. Despite a consensus around their inefficacy at least in the current moment, I found a widespread conviction that bioinoculants will work in the future and constitute an important technology for the achievement of sustainable agriculture. If bioinoculants can provide the nutrients needed by crops, the argument goes, they will significantly contribute to the reduction of fertiliser use. There is therefore a sense that the solution will succeed in the future.

Grace, a professor working at a prestigious university, leads a group focused on the functioning of the symbiosis between plants and particular soil fungi. Her object of study shares a number of features with microbial research, including the fungi's association with plants and their scale and invisibility: 'you don't see it with a naked eye, you need a microscope' (Grace, scientist). Grace is also a technology and future-oriented scientist interested in expanding and implementing the use of bioinoculants as well as the occurrence of a beneficial symbiosis between plants and microorganisms 'into agricultural practices' (Grace, scientist). Unlike Joseph, who recognises that 'there is a lack of communication between science and farmers' (Joseph, scientist), Grace is proud of the ways in which she informs farmers about bioinoculants by giving presentations. I read this difference as motivated by her stronger technological enthusiasm and optimism for the future linked to her participation in a large project funded by the Bill and Melinda Gates Foundation[13]. The research looks at manipulation and engineering of new symbioses between plants and microbes so that nitrogen fixation can take place beyond the family of legumes, in what she considers 'a fantastic concept' (Grace, scientist). Grace's narrative around this 'big dream' is strikingly focused on the future promise of the field and it shows a strong belief in microbial life as a technological solution to contemporary agricultural challenges.

> I'm extremely hopeful, I'm participating in a big network ... one big dream has been to be able to transfer this nitrogen fixing association to other plant

[13] The Foundation has been scrutinised for a solutionist thinking, a way of operating focused on results, using policies that have been shown not to work (McGoey, 2015). Its global influence on healthcare, education, patent protection and foreign aid is considered problematic, while its investments in agriculture and large companies such as Monsanto are denounced for aggravating food insecurity.

> species ... engineering this kind of interaction into the cereals ... this is one of the most potent projects that we have to try to actually engineer, if you wish, biofertilisation. (Grace, scientist)

Grace also sees the possibility to protect crops from parasitic plants through technological intervention 'by knowing how to interfere eventually with some of those signalling mechanisms' so that 'you can maybe even accelerate the establishment of this nutrient-enhancing symbiosis.' (Grace, scientist). She is determined to correct what she considers a limitation in the symbiosis between a plant and a fungus that may not take place when the plant has enough nutrients: 'if we can unblock this then we can use the fungus much better as the biofertiliser' (Grace, scientist). By referring to natural processes as blockages, Grace clearly positions her work as part of a project that interferes to overcome the obstacles posed by nature.

An equally enthusiastic attitude to bioinoculants surfaces in Isabel's account. A molecular soil ecologist, Isabel considers the agricultural and environmental role of her field, looking at ways to 'have more plants out of an amount of soil but also to reduce emissions' (Isabel, scientist). Bioinoculants for her are 'one of the best' and 'most interesting' technologies, however 'maybe the technology is not there yet' (Isabel, scientist). The promissory agenda she promotes emerges clearly in the acknowledgement that the technology is not ready *yet*, in the present moment, with the expectation that it is only a matter of time before it will be improved, once again introducing a temporal aspect in the employability of microbial communities in the future. Because bioinoculants and other technologies are currently not ready, this optimism supports the belief that the next technology will be the one that provides a solution. Bioinoculants need multiple strains to be beneficial and they require complex engineering to keep the microbes alive in a new environment. The challenge of their efficacy is considered the competition between the new bacteria and the ones already present in the soil. Current bioinoculants are 'crushed by the other microbes in the soil' (Isabel, scientist), thus Isabel hopes for a future when bioinoculants will contain multiple strains of bacteria so that they will be more likely to persist in the new environment.

> Now they try to sell one strain of bacteria but I think the future will be like a mix ... it would be a way to help [bacteria] stay longer so they can actually benefit the soil ... the technology is getting there but not yet, so that would be a really important field. (Isabel, scientist)

Similarly, for Jack, a molecular microbiologist, the inoculant has 'been adapted over generations to survive in the soil that it came from, you're putting it into a new environment ... and it's got to compete with all those other organisms that are already there and already adapted to that environment' (Jack, scientist). To explain the challenge faced by the bacteria inoculated in a new environment, Jack resorts to the neo-Darwinian[14] metaphor of competition and survival, with narratives of adaptation, displacement and of natives versus foreigners. The microbial communities emerge as entities in need of protection from what Jack defines 'indigenous populations' that will outcompete the beneficial microbes. This narrative of competition also connects with a long term question around who will survive and it therefore underlines the futurity of these evolutionary accounts.

> If it's released into an environment that it isn't familiar with or hasn't adapted to, then the chances are it may not survive, so it may be there for a few weeks or a few months but, on the long term scale it may not survive, so it's got to outcompete, compete all the indigenous populations that are there. (Jack, scientist)

Jack does not object to the manipulation of microbial life per se but to the inefficacy of transplanting communities in new environments where they will not survive. Because of this issue, to the use of bioinoculants he prefers the possibility to manipulate the plant, an inclination shared by Ben, a plant and soil microbiologist who questions the actual necessity of bioinoculants because he believes that what is needed may already be in the soil: 'the key thing with the inoculation is whether or not [it] is actually necessary at all' (Ben, scientist). Like Jack, Ben suggests an alternative strategy to inoculants, an intervention directly to the plant root that 'can

[14] Neo-Darwinism is a theory maintaining that 'random mutation is the major source of evolutionary change' (Margulis and Sagan, 2002:214).

attract the microbiome' it needs 'already present in the soil' (Ben, scientist). In this sense, Ben is open to different approaches that include the manipulation of the plant roots, so that plants can themselves attract the microbes they need. Ben ultimately believes in 'the use of the microbiome' and all the technologies that allow to intervene specifically in different parts of a field rather than spreading fertiliser indiscriminately: 'all of these things are great' (Ben, scientist). Ben also shows a strong microbiopolitical characterisation of control of the perfect timing, dosage and quantity of microbes needed for agricultural purposes.

> The long term strategy might be crop manipulation to actually manipulate for example its root exudate profile ... if we can amend the plant in some way we can actually recruit what's already present in the soil ... trying to get things present in the right place at the right time and at the right dosage. (Ben, scientist)

Ben states clearly that the use of microbial communities can assist in achieving sustainability: 'we can hopefully use microbes in the soil to actually contribute towards a sustainable intensification of agriculture' and he thinks of soil as a 'big reservoir of microbes' that 'can be selected' (Ben, scientist). Ben believes that microbes can 'do a job for us' thus confirming Granjou and Phillips' characterisation of soil microbial organisms as agricultural labourers (2018).

> If we can actually enhance and harness I suppose these microbes to get them to be at the right place at the right time then they can actually do a job for us in terms of growing crops ... we can actually reduce our dependence on agrochemicals. (Ben, scientist)

These accounts show the presence of a promissory agenda oriented towards sustainability solutions for the future of agriculture. They also demonstrate an assumption around the importance of human needs and the ensuing endorsement of microbial manipulations that are seen as able to meet them, to which I now turn.

Microbial services

The proposal of technological fixes to address agricultural and environmental challenges emerges in connection with the constitution of a human-centred narrative around the exploitation of microbial services. This characterisation implies the priority of human benefits in relation to microbial technologies. Human exceptionalism, with its roots in the separation between humans and other animals and the ideal of the human as a bounded agent, implies that its interests are superior to those of others (Latimer, 2013). This dynamic allows for an asymmetrical relation with nature, a realm seen as in need of management and intervention. In the study of the microbial communities of soil, human exceptionalism emerges in the assumption that human needs in food production and the solution to environmental damage caused by intensive agricultural practices take precedence over the consideration of microbial life as valuable. This human-centred narrative manifests itself in exploitative attitudes towards microbial organisms and the proposal of technoscientific interventions such as bioinoculants and the engineering of new symbioses where microbial communities emerge as mere services.

Human-centred narratives are not only present within the scientific domain but they traverse fields, reaching food growing projects with environmental and 'microbial' sensitivity. This is evident at a small food growing cooperative where growers are interested in building a relationship with the land and they talk about microbes with fascination. These elements however do not necessarily entail a rejection of an anthropocentric perspective. On the contrary, at times they allow the exploitation of the work that visible and invisible life forms are seeing as performing for human benefit. When discussing the decision not to use tractors, cooperative grower David jokes that 'we did use pigs' and 'that worked quite well ... we could see the potential in using livestock' (David, grower). Similarly, the growers use certain animals as pest controls ('for slugs we've got ducks') and horse manure to feed the soil. David recalls some concerns they had in the past about the use of manure because of the possibility of it containing hormone residues used to treat the horses' worms, as well as 'bits of rubber'. David states that he was less concerned than others because 'as long as you're building up the soil that's the most important thing' (David, grower).

This shows how environmental concerns for the state of soil can still entail the exploitation of other organisms visible or otherwise. In considering pigs, horses and ducks in their instrumental exploitation, David embraces an ethics that is mainly human-centred. The cooperative follows the principles of permaculture, a set of agricultural practices designed by mimicking and observing nature that poses itself as a slow, long term alternative to industrial monoculture agriculture (Wallace and Carruthers, 2018). While permaculture, as an ethics of care of the everyday practice related to the earth, may entail a decentring of the human and the idea that personal and collective are related in the practice (Puig de la Bellacasa, 2010), in this particular growing project embracing permaculture does not result in a practice that counters human exceptionalism. In the same way that several soil microbiologists seem at ease in an instrumental relationship with their object of study, David focuses on other life forms small and large as instrumental to his growing practice. This works as a reminder that forms of knowing that pose themselves as ethical conduits for social change are not necessarily centred on the intrinsic value of soil and its life but can present themselves in anthropocentric forms, where change is regarded important only in human terms.

Human-centred understandings of the microbial as an entity that provides services for human benefits emerge strongly also in policy discourses, even in the more progressive accounts that focus on soil health. This narrative takes an anthropocentric tinge when it assumes a view of microbes and soil as merely instrumental entities to harness for human use. For instance, the conversation I had with Naomi, CEO at a cooperative development agency and chair of a food board, highlights how official food strategy discourse remains focused on issues such as childhood obesity rather than soil health and sustainability. While she is aware of the need to focus on soil health and she claims her colleagues are too, a human-centred narrative permeating media and policy realms does not allow for a wider approach that considers the value of soil and biodiversity.

In order to explore the pervasiveness of a human-centred narrative in policy discourse, I analyse two recently published reports that refer to the microorganisms living in soil. In discussing these documents I am particularly interested in the way

they constitute microbial life. These documents are in line with the UK government's recognition of the need to address and monitor soil degradation through indicators including the 'biological activity in the soil' (Defra, 2018:43) because of the increasingly acknowledged risk of agricultural land 'becoming unprofitable within a generation' (House of Commons Environmental Audit Committee, 2016:3). Following Lindsay Prior's argument on the limitation of a social science that considers documents purely as mute containers of information that make content available, I approach these texts by considering the actions and functions they perform and in particular what they do for the possibility to think about a decentring of the human and a repositioning of its role within the environment (2008). By asking 'questions about what documents do' (2008:832) and the functions texts perform, I consider the documents as illustrations and demonstrations of how the soil microbiome emerges and is enacted within the regulatory and policy field.

The 'Unlocking the microbiome' report was published in 2017 by the Microbiology Society (Microbiology Society, 2017), a 'membership charity for scientists interested in microbes', based in the UK (Microbiology Society, 2018a). In recent years, the Society has published a number of reports and briefings on all aspects of microbiome research, including the soil. The 'Unlocking the microbiome' report was the result of a number of multidisciplinary workshops informed by 'around 160 stakeholders, including representatives from academia, industry, government departments and agencies, and research funders' (Microbiology Society, 2018b). The report is addressed to the Microbiology Society's members rather than other stakeholders. The broad representation in the workshops informs the set of recommendations that can be seen as directed to the Society's members themselves.

The report calls the scientific community and therefore its own authors 'to take a coordinated and constructive approach' and 'to work together in sharing data, skills and expertise, crossing disciplinary boundaries, and building effective communities' so to 'unlock the potential of the microbiome' (Microbiology Society, 2017:3). A section titled 'Agriculture and food' in particular refers to the soil microbiome and the microorganisms living in the rhizosphere, the narrow zone of soil surrounding plant roots. Harnessing the soil microbiome is seen as relevant to 'improve

agriculture and food productions' through interventions such as microbial inoculation, 'bioengineering symbioses' and 'new on-site technologies' to examine food related disease (2017:8). Thus the potential of the microbiome emerges in the technological and anthropocentric uses it is seen as performing.

A further section titled 'Biotechnology' considers the usefulness of the microbiome in 'develop[ing] the bioeconomy' and it highlights current research to 'understand, monitor and exploit microbiomes', showing the microbiopolitics at play in the policing of a microbial life in need to be managed and used for the development of biotechnologies (2017:9). In noticing the language used, the choice of words like 'monitor' and 'exploit' demonstrates the regulatory and anthropocentric orientation of the field, focused on the necessity to control and manipulate microorganisms for human benefit. The connotation of these terms does not leave room for conceiving an engagement with the microbial soil beyond microbiopolitical management. The report also calls for international interdisciplinary research for 'translating this knowledge into new products and interventions' (2017:11), thus underlining the importance of collaboration across disciplines to facilitate commercial products and 'novel microbiome discoveries and biotechnologies' (2017:16). The title of the 'Unlocking the microbiome' report itself suggests an idea of microbial life as having a potential to uncover and make visible, a mysterious nature in need to be revealed and valuable for its anthropocentric applications. The promissory agenda emerges strongly in the drive for technological solutions the microbial communities are seen as able to offer.

A section of the report includes 'all forms of life on Earth' as those who benefit from the microbiomes of soil and ocean, thus making this field of research important in 'restoring or managing important microbiome functions' (Microbiology Society, 2017:8). However, this call still appears to relate to human needs such as tackling antimicrobial resistance and infection control. In this context, the soil microbiome emerges as an object of enquiry that constitutes a means to an end, significant for its application and not for its own sake. The report reinforces the idea that understanding the microorganisms living in the soil is beneficial for human use and this is how 'Unlocking the microbiome' co-produces the soil microbiome as an entity

valuable for what it can offer to human societies. Therefore the report contributes to create an entity that matters as a tool for the development of technologies, products and ultimately for human use.

The second document I consider is the 'Soil Health' report published in 2016 (House of Commons Environmental Audit Committee, 2016). The Environmental Audit Committee, whose remit is to assess and audit governmental policies' contributions 'to environmental protection and sustainable development' (2016:iv), launched the Soil Health enquiry at the end of 2015 due to concerns around the detrimental effect of soil degradation for farming, flooding and climate change (Parliament UK, 2015). The enquiry invited submissions of evidence aimed at addressing policy solutions to soil degradation and it was based on the critical perception that 'current measures do not give sufficient protection for soils' (2015). The enquiry relied on written evidence from a number of academics, farmers' representatives, research centres, programmes and organisations and published its report 'Soil Health' in 2016 (House of Commons Environmental Audit Committee, 2016). The report declares soil a 'forgotten component' of 'human life and society' long neglected within environmental debates, in an emphasis on the lack of attention to soils (2016:3). Among the concerns explored by the report are the consequences of soil erosion in terms of profitability, damage to the environment and increased carbon emissions. The report also points to the lack of focus on soil structure and soil biology in the government plan to achieve soil health and it lists 'living forms' and 'biological activities' as some of the crucial components (2016:6), thus showing the shift towards an increasing recognition of the relevance of the ecology of soil in policy discourse around soil health. The report also calls for proactive actions aimed at soil improvement rather than damage limitation as well as for educating and supporting farmers on practices aimed at soil health.

As with the previous text, in analysing this document I examine the actions and functions it performs rather than looking at the text as a container of information. I am interested in exploring what this document does to and for an understanding of microbes as an instrumental entity or in terms of a potential decentring of the human from its primacy position. In looking at how the report shapes the relationship

between humans and soils, it is worth quoting from the introduction: 'Soil is home to a quarter of the earth's biodiversity including earthworms, fungi and bacteria which maintain its fertility and provide raw materials for the medical industry' (2016:5). The life of soil is given prominence and relevance, but for the sake of the benefits it provides for soil fertility and the medical industry. These purposes, strictly related to food production and healthcare, suggest that biodiversity is relevant in so far as it supports human needs and only secondarily for the wellbeing of plants and nonhuman animals. Despite the clear recognition of the microbial life of soil as important, the report confirms once again human demands as superior, more relevant and urgent than any ecosystem living in and from the soil.

The report deems soil crucial for its 'essential services to society' (2016:21), thus showing the influence of the ecosystem services framework in how policy and science approach the value of soil. Although the final recommendations urge to 'move away from viewing soil merely as a growth medium and treat it as an ecosystem in its own right' (2016:39) the report appears to promote this ecosystem mainly for its profitable role in public health and agriculture. This is in line with the ecosystem services approach based on the Millennium Ecosystem Assessment (2005) a four year process that explicitly and uniquely assessed ecosystem services for how they contribute to 'human well-being'. In this sense, the recommendation to consider soil as an ecosystem does not ensure a disinterested concern. By proposing that the soil and all its earthworms, fungi and bacteria are there for humans to exploit, this document contributes to reinforce the prominence of human interests in the study of soil microbial communities.

Granjou and Phillips have found anthropocentrism not to be the only element characterising soil microbiology, as the field can go beyond a mere production-based or human-centric focus and offer possibilities to be oriented to new relationships with the nonhuman (2018). While I argue that these types of decentred relationships are present among soil microbiologists, growers and even policy experts, they are certainly absent from official policy discourse. This is because, as noted, policy has adopted a strong ecosystem services framework to consider the value of soil and other natural resources. The ecosystem services approach is useful in communicating

the importance of soil and its ecosystem and in making these relevant in policy making, but it reinforces a discourse focused on the use and employability of these organisms, depicted as able to provide the services needed to achieve sustainable agriculture.

Drawing on Heather Paxson's concept of microbiopolitics and the post-Pasteurian movement that focuses on collaboration between humans and microbes, conceptualised as allies rather than as threats in need of medicalisation (2008), these documents can also be seen as showing a microbiopolitical characterisation of microbial life located between appreciation and safety management, in a drive towards control and exploitation. Overall, the documents do not go beyond the primacy of the human and do not consider 'other animals and other life, including plant life and fungal life, as having intrinsic value as equal to ours', in the words of Matt, a horticulture teacher. On the contrary, the documents contribute to the emergence of an anthropocentrically relevant microbiome that lends itself to become a technology employable to address agricultural and environmental challenges. It is in this sense that alongside a strong technoscientific and future-oriented constitution of the field, soil microorganisms are also implicated in an anthropocentric narrative that traverses scientific, growing and policy domains and that constitutes them as mere services for human needs, placed unquestionably above other organisms.

Slower times

Technologically convinced stances and views of microbial manipulation as a future solution for sustainable food production coexist with an element of reticence and radical critique towards technoscience. In this section I consider a slower pace present in the field of human/soil relations, permeated by a degree of resistance to these interventionist characterisations. As I will show, these stances consider technologies as taking the attention away from long term change that entails growing food without depleting the soil. Interventions such as bioinoculants are seen as distractions from the real issues facing UK agriculture. There is a sense that only addressing more fundamental concerns can result in the systemic change advocated

by the experts interviewed. Those holding these positions propose slower solutions to food production and environmental damage. They envision a version of the future not driven by high tech but by how things were done before interventions and technologically mediated relations with soils. Critiques to technoscientific solutions are present across areas of competence, among scientists, policy experts and growers. These positions are grounded in the experts' degree of ethical investment aimed at transforming food production in ways that benefit biodiversity, the soil and the community. They are associated with a political engagement and a commitment to change the food systems and agriculture. As discussed in the previous chapter, I embrace the complexity of these ambivalent relations by avoiding categorisations and distinctions between epistemological spaces, looking instead for transversal and contradictory positions within and across areas of expertise.

An instance of the ways in which ambivalence traverses communities of practice is epitomised by Ben, described in the previous section as a scientist who embraces the use of microbial communities in any technological manifestation that can achieve sustainability in agriculture. Alongside holding a highly technological orientation, Ben also presents something different, a somewhat nostalgic element in his discussion. While he is focused on the future promise of microbial life, he also relies on the temporality of soil in the idea that things were better in the past, before human intervention. He mentions the possibility of harnessing lost 'beneficial microbial interactions' that were in place 'before domestication of plants' and 'the use of lots and lots of synthetic fertiliser and other agrochemicals' (Ben, scientist). In this nostalgic narrative, unusual for a scientist, Ben hopes that 'it's possible to turn the clock back and actually re-engage the microbes with the host' (Ben, scientist). Ben seems interested in exploring a relationship between plants and microbes that was in place before human interventions. This element is in stark contrast to the future-oriented narrative Ben previously proposed, as well as to the evolutionary vision embraced by Jack. It is this ambiguity that locates the study of soil microbial communities in balance between a past of lost beneficial interactions that 'might have actually gone away' (Ben, scientist) and a promising future when these old associations are re-established through technological intervention.

While the scientists referred to in the previous section are mainly concerned about the current inefficiency of bioinoculants, Nicholas, a professor of environmental microbiology, proposes a more radical scrutiny. He is convinced that adding a microbial product to the soil is not sound on more fundamental grounds because it does not deal with what he sees as crucial issues in the agricultural system. Nicholas believes that bioinoculants address the symptoms rather than the cause of soil depletion and his view presents both hope and concern for the use of these products. While he accepts their possible employment in the future 'in making farming more sustainable and better for society, better for the environment' (Nicholas, scientist) thus still aligning with the temporal orientation of this field, he then proposes a more radical rejection of these products in depicting their likely detrimental effects, lack of safety and use as quick fixes. Instead, he stresses the importance of 'getting to the real issues' implying that inoculation represents rather a shortcut that comes too late, when the damage to the soil is already done, while he is interested in addressing the root of the problem. Nicholas believes these interventions avoid more fundamental solutions and do not address the issues in the agricultural system in the long term.

> I also worry about using inoculants as quick fixes for things and really, it's about getting to the real issues and trying to resolve the real issues to do with how soils work rather than just add an inoculant, ... they probably play a role, inoculants in the future ... as long as it's handled effectively … the issue is where is that inoculant coming from? Can you predict its function in the ecosystem? ... it's completely unpredictable at the moment so it's like a bit of a wild west to me that I'm, especially when it comes to things like bacteria or fungi, then I'm not so keen at the moment. (Nicholas, scientist)

Nicholas' perspective seems in line with wider critiques to interventionist narratives that assume new technologies will solve issues concerning soil, agriculture and the environment. These orientations have been denounced within soil science and

agroecology[15] for constituting a reductionist 'therapeutic approach' where each event is looked at individually and the symptoms of a detrimental system are depicted as the problem (Magdoff, 2007:110). According to these critiques, soil erosion, depletion and nutrient deficiency need biological restoration and are symptoms of wider issues such as deforestation, monoculture and the use of chemicals (Rosset and Altieri, 1997). Following the therapeutic metaphor, these politics of intervention can be understood as having what in the medicine realm Ivan Illich referred to as iatrogenic effects, seen when increased medicalisation has detrimental health consequences and eventually results in more disease, fear and death (1976).

Early career researcher Emily also advocates fundamental change that she believes can lead to an improvement of soils. While she thinks technology can be useful to correct the current failures in the farming system, like Nicholas she would rather address more fundamental root causes. In this sense, she implies that a willingness to tackle the source of the problem would make certain technologies redundant. Emily links directly her lack of interest in new technologies to her views on small scale growing, thus interrelating a rejection of technoscience to an appreciation of permaculture.

> I'm not anti-technology cause I think we need it to work on a big scale but I'm really biased towards permaculture and small scale gardening and small scale growing, so I tend to kind of not looking into the technology side of things. (Emily, scientist)

In her work, Emily uses DNA technologies to look at how microbes within the rhizosphere interact with the plant root. In this sense, her interest in permaculture, a movement that proposes an agricultural system that mimics nature (Wallace and Carruthers, 2018) and her rejection of technology are grounded in her conviction that environmental issues are caused by unsustainable agricultural practices rather than in the specific practice of her work. This also suggests that the diversity of positions

[15] A discipline that 'emphasizes the interrelatedness of all agroecosystem components' including farmers' and people's knowledge of ecosystems (Rosset and Altieri, 1997:290). It is considered by its supporters as able to promote sustainability in agriculture.

among the same community of practice is related to the experts' political worldviews and their investment in social change. As mentioned, these critical views traverse expertise and are found also among policy experts like Kevin, a communication officer at a soil programme. Kevin shares with Emily and Nicholas a sense of technological dismissal. He is not convinced about the use of interventions such as precision farming[16] and he perceives the gendered nature of a fascination with new technologies such as drones that he sees as toys.

> We don't work on kind of any technological stuff ... precision farming and, I don't know too much about it to be honest ... I have to say I'm not that interested in robotics or drones ... apologies for saying something sexist, whenever I see a drone I just think boys with toys, it's just like men playing with toys ... I would rather see some kind of more fundamental changes about looking after the soil rather than just trying to make the system we have, which we know can't go on, more efficient. (Kevin, policy expert)

Kevin believes that new technologies constitute only problematic shortcuts that do not allow for long term solutions in agriculture to be pursued. In contrast with the technologically-oriented scientists, Kevin, Nicholas and Emily propose a different version of the future and advocate for a broader view of social practices that affect soils rather than focusing on the mere manipulation of soil and microbial communities.

Andrew, a professor of food and health policy, is also concerned about the unknown consequences of microbial technologies that are being tested 'live', where inoculants are introduced with no clear identification of their possible consequences. Andrew sees technology as uncritically and widely accepted because it offers a 'magic' quick fix that avoids more durable solutions or it creates problems that it can then fix. Andrew is also oriented towards the future, but he proposes different solutions and versions of the future that do not include technoscientific interventions.

[16] An agricultural tool defined as 'a management system for farms that aims to improve productivity and resources use ... it enables precise and optimized use of inputs leading to reduced costs and environmental impact' (Balafoutis, et al., 2017:22).

> I do feel sometime we're living in a live experiment, that we don't know what the consequences of this are in the long term, ... I think we need to be careful of technology ... the tendency of science is to look for magic bullets ... I really worry about that. And I'm not sure we've got safeguards in place. (Andrew, policy expert)

Similar positions against the use of new technologies are proposed by growers I interviewed or worked with during my ethnographic observations at the cooperative. These small scale growers see microbial and other interventions as avoidance strategies that do not deal with what they consider the real issues. Instead, the growers advocate for solutions that they see as slower compared to the quick fixes of technology. In this way they contrast a technologically-oriented perspective to the slowness of soil and growing practices. Their temporality therefore is more in tune with the constitution of soil as a slow material of decay and it shows a contrast between short term quick fixes and slower, long term change. Following the materiality of soil in its temporal rhythm, these growers counter the fast pace of high tech inevitably out of tune with the course of soil formation.

This is the case at an organic twenty-acre farm based in South East England, well known in the organic community for its ethical and environmental commitments. I was familiar with the farm prior to the start of this project and I visited on several occasions as this is where I source my own produce. As part of my fieldwork, I had the opportunity to do a three-hour farm visit and an interview with Neil, the main grower. The visit included walks along the fields, the greenhouses, the tool building and woodchip piles; it involved detailed explanations of processes and methods employed at the farm.

Neil believes in the capacity of soil to regenerate itself and he values small scale and organic agriculture focused on the protection of soil and its life. He rejects the commercialisation of microbial products as 'technological fix' and unnecessary external inputs.

> All companies want to sell these bacteria to farmers and growers because it's going to do their soil some good and that's not really the right approach

> because the soil can do this on its own, you don't need to put anything into your soil at all if you look after it properly. (Neil, grower)

Neil believes that soil is a 'remarkable medium' that contains the resilient capacity to recover if given respite from anthropogenic damage and exploitation. In a transversal affinity between different worlds and communities of practice, Neil seems to converse with technoscience-oriented scientist Joseph. While, as seen in the previous section, Joseph considers his field as a story of tomorrow, he also shows an ambivalence between embracing technology and caring for the farmers who he sees at the receiving end of commercial microbial products that may not work. He believes it is important to communicate to farmers 'the line of study we pursue for the future ... what would be possible in the future', but 'that's a story of tomorrow' (Joseph, scientist). In considering the promissory future of the field, Joseph places farmers' trust in the present.

> There are companies selling them some inoculants ... but we need to be scientifically accurate that they may or may not work ... we cannot let them down with selling things that are not working ... that may result in farmers losing trust and that is the most important thing. (Joseph, scientist)

In his concern for farmers' trust, Joseph demonstrates to value the human relationship with those working in agriculture, seemingly putting their interest before possible research outcomes aimed at the commercialisation of microbes. Joseph and Neil agree in their critique of the sale of microbial products to farmers, thus showing how their concerns cross over fields rather than being affected or isolated by their practices. Unsurprisingly, Neil is more radical in placing soil in a sociopolitical context and imagining a food production where machinery is not essential, thus proposing a vision where everyone plays a role in agriculture.

> Certain aspects of technology are hugely overrated ... if we had to we could produce food with no machine input whatsoever, we can do that but it takes more labour input to achieve ... So, if we're talking about seriously increasing food production for the world then get rid of all machines and do it all by hand

> but that means everybody has to do it, you can't have just a few farmers do it, everybody has to partake in that process. (Neil, grower)

The tools and technologies Neil uses at the farm are relatively basic. He employs an old cement mixer to combine the compost ingredients and then sieves the compost manually (Figure 7). Compost, decomposed organic matter used to enrich the soil, is an important component of Neil's way of farming. By producing the compost on site, he is able to protect his soil while eliminating external inputs such as manure thus lowering the carbon footprint of the farm in terms of transportation.

Figure 7: Neil's compost sieve

Neil considers observation and learning from nature as practices with direct applications that keep him in direct proximity to his fields. This emerges for instance in the way he deals with pests and their behaviour, that contribute to form his relations with plants and insects. Neil shows me a field of Brassica plants he has left to go to seed. Their yellow flowers matter to him for more than one reason: they are beautiful and they encourage pollinators in the field. But these plants also allow *Cotesia glomerata* to overwinter on them. This small wasp is a predator of a caterpillar, the avid Brassica's eater *Pieris brassicae*. By letting the plants continuing their life cycle once the harvest is concluded, Neil allows the overwintering wasp to develop and 'take care' of the caterpillar in the coming season. This is an instance of 'learning from nature' that entails letting plants follow their life course as they contain within themselves the very solution to a possible pest problem. Neil claims to have achieved this understanding through experience and observation.

Figure 8: Brassicas in flower at Neil's farm

Alice, a grower based at a city farm, also stresses the importance of looking at what she considers the issues concerning soil and agriculture rather than tackling the symptoms by using technology: 'we should just deal with the problems first' because 'the questions been asked are the wrong ones' (Alice, grower). She also hints at the temporal rhythm of soil, with the approaching winter seen as an opportunity to slow down and be able to dedicate herself to other projects, such as reading up on soil microbes: 'as winter comes I'll have a bit more time to look into it' (Alice, grower). This temporal element is also perceived by Steve, a grower based at an urban growing space, as a sense 'that the natural world is kind of a large rhythm', where a connection with nature is characterised by a periodic rhythm and the aesthetics that he can see (Steve, grower).

> This time last year we cut back the brambles, we're doing this again this, same time the following year so there's kind of a sense of being part of a bigger cycle of I don't know a natural cycle ... talking about the natural world and admiring it and taking pleasure in seeing what you see. (Steve, grower)

Cooperative grower David does not necessarily reject technologies as long as they are sustainable, which for him means connected to natural cycles, renewable, effective and not dependent on fossil fuel. He considers the risk of abusing technologies, an awareness in line with a sense of danger in losing contact with soil and nature, while he is keen on 'relearning what we've kind of lost, we've lost a lot of knowledge' (David, grower).

> There's a huge role for appropriate technology, the right level of technology, in working in the right steps ... it's about not abusing that technology ... it's trying to utilise the ones that work for you and always being aware of how sustainable they are. (David, grower)

More critical, cooperative worker Peter considers microbial products aimed at increasing soil fertility as shortcuts not dealing with the real issues, quick remedies used by conventional farmers only willing to see immediate results. He instead proposes a slower approach to growing that requires time, hard work and nothing else, although occasionally he seems to acknowledge only the human effort in the achievement of a healthy soil and not the hidden work in the soil itself. Against what he considers a 'fast and easy' narrative embraced by conventional farmers, Peter presents a stark reality of physical (and noble) agricultural work.

> To have microbes in your soil you don't need anything, you just need common sense and a bit of work, that's it. We don't need that stuff. It's just a way for farmers to make it easier, faster and easier. You're not supposed to be fast and easy, ... you have to work, you have to bend down to work, ... no, you don't need anything, you just need to look at nature. (Peter, grower)

At the food growing cooperative where Peter works and where I volunteered for six months, practices of soil management speak clearly in favour of an approach to soil that minimises advanced technological interventions. Most if not all tasks are carried out manually by workers and volunteers, from sowing seeds to planting trees and weeding. These slower methods are in tune with the growers' close relationship with soil. Compost making is carried out by adding and mixing the ingredients with the assistance of a fork or a spade. The employment of this manual technology shows and reflects a conceptualisation of the slow pace of soil in place at the cooperative. Drawing on Paxson's work, it can be seen as representing a post-Pasteurian attitude that embraces the assistance and benefits of microbial life.

Figure 9: Compost making at cooperative: manual technology

Figure 10: Compost making at lab facility: machinery

This post-Pasteurian way of composting contrasts with a state-of-the-art facility I visited where soil microbiome research is carried out. The facility employs a compost mixing machine using as one of the ingredients a chemical aimed at eliminating possible pests (Figure 10). The microbiopolitics of soil life emerges through this machinery as a Pasteurian characterisation of the microbial based on management and safety control. As the level of technology moves from manual spades to clean machinery and from bodily closeness to distance and separation, the attitude towards microbial life becomes one of control and detachment. Attempting to overcome the distinction between meaning and thing involves seeing these objects for their meanings, namely thinking through things that participants think through in order to understand their worlds (Henare, Holbraad and Wastell, 2007). Spades and

machines then become objects of meaning that speak clearly of the microbiopolitics of both management and appreciation of microbial life. This is how the soil microbiome field is complicated by an entanglement between contrasting technological orientations and attitudes of control, recognition, proximity and distance.

In turn, the critiques of utilitarian understandings of microbial communities considered in this section are often portrayed in soil science and microbiology as an obstacle to advancement and as nostalgic attempts to return to the past and to a romantic idea of nature. The already mentioned biotechnologists de Oliveira and Van Montagu construct a dichotomy between rationality and public fear and argue that the inevitability of intensive agriculture and the urgent need for innovation and biotechnologies is obstructed by a new 'fundamentalism' that is 'opposed to human intervention in the natural world' and is taking humans back to the Middle Ages (2015:137). Their strong position resuscitates the tension between scientific rationality and popular superstition, where opponents to new technologies are charged as nostalgic and naive. To these dynamics, Stengers opposes the idea of 'slow science' as a form of resistance to competitive and immediate science, a science that does not need to stop time, but that is currently relevant (Stengers, 2011).

Against the criticism often reserved to those who challenge the advancement of technoscience, Deborah, an early career researcher who looks at how microbes decompose crop residues, defends the right to be conservative, that is the right to advocate for conservation rather than for reactionary politics: 'I'm a little bit conservative [laugh] ... we don't need to have negative connotation with conservative just because of politics [laugh]' (Deborah, scientist). Deborah is influenced by the common vision of land ownership that remains a symbol of independence and offers a strong dream about autonomy from a controlled workplace (Scott, 2012). By being in touch with the 'hippy farmer inside me who wants to just have a farm with some animals', Deborah seems to consider the possibility of leaving her career in science in order to pursue a wider dream of connection with nature when she gets 'fed up with universities and bureaucracy'

(Deborah, scientist). In this sense, she shows how her world view is not limited to the scientific realm and she does not consider her role of scientist as rigid, but it can expand to wider subjective experiences. Deborah is open to the possibility of a trajectory from the scientific to the growing endeavour, not seen as separate worlds but as part of a continuum. Her position is not necessarily influenced by the specific research she is involved with, but by an ethical commitment to change land use towards more sustainable practices. In a conscious embrace of a different idea of soil and nature that is holistic, Deborah does not advocate for a romantic return to the past but for actual change in the current farming system, towards small scale growing.

> Alternative permaculture practices, they just work well, we can't expect that we can intensively farm the land and have lots of carbon, no you can't have it all. ... We know a lot about how to farm in a way that does take care of the soil. It's just not for large production. ... We shouldn't forget to look at the whole picture, to look at things holistically'. (Deborah, scientist)

For Deborah, not only large scale intensive farming and ploughing are detrimental to the soil, but technological innovations for food production such as hydroponics[17] do not represent real solutions but distractions from much simpler and more essential change in agriculture.

> The most efficient system is nature [laugh]. Converting the sun into electricity, making LED light and then trying to find the right wave lengths that the plants require so that it mimics the sun, it doesn't make any sense. (Deborah, scientist)

Like Deborah, cooperative horticulture teacher Matt is aware of the accusations of 'being regressive and conservative' often received when contrasting what he sees as a profit-driven economic system and proposing instead to prioritise human labour over technological 'labour-saving devices' like tractors and other innovations (Matt, horticulture teacher). In his radical politics, Matt points out how far from nostalgic his food growing cooperative is, because it engages with people and 'it's not turning

[17] A technology in which plants are grown in a nutrient solution without soil (Jones, 2005).

its back on the city' (Matt, horticulture teacher). For Matt engaging with people is the point where working with nature ceases to be conservative and becomes a force for social change. In this sense, unlike Deborah, he clearly rejects the idea of conservativism. Matt also hints at an ideological contrast between a perceived conservative countryside and a more progressive urban life linked to resistance and social engagement, a contrast Jon Agar considers still present in Britain where the countryside and 'wilderness ... have a relevant history as a cultural construct' and can still be seen as unspoiled and coupled with nostalgia for the rural environment in opposition to the urban (2018:10). Leveraging this narrative, Matt argues that the cooperative is 'a really useful demonstration of not being regressive, it's not going off and being conservative in the countryside and being isolated' (Matt, horticulture teacher). On the contrary, its role is precisely engagement with the community and reconnecting people with nature within the city. Matt and Deborah both reject technoscience and are acutely aware of the charge of nostalgia they face in doing so. However, Deborah does not decline the idea of escaping to the countryside whereas Matt considers this possibility to be inherently and politically conservative, showing how these positions are not monolithic but present nuances and differences.

Reconnecting with soils

Through these discussions, another related theme emerged, associating the criticism to technological interventions such as bioinoculants and microbial manipulations to the question of reconnecting with soils on a more fundamental level. Critical attitudes found among my participants show an ethical concern around a perceived separation between people, soil and food, seen as in urgent need to be addressed. For a number of participants, the rejection of technoscience and the recognition of the importance of addressing the root causes of agricultural issues are grounded in the conviction that a fundamental relationship between humans and nature has been lost. The understanding of what counts and constitutes nature implicitly includes the relationship with land and food as well as a nostalgic idea of what once was and no longer exists. Within the perceived missing connection between people and nature, technology is regarded as the element that reinforces and deepens this

loss in human experience. Unproven technologies in a variety of manifestations are then rejected because they are seen as able to further the already concerning distance between humans and land. As I will show, the unease around a lost relationship with soil and food crosses over competence and expertise in this disputed field and is shared by small scale growers, policy experts and scientists. Thus, it is not grounded in the membership to a specific community of practice and cannot be understood by simply separating the spheres of belonging. The concern is instead related to alternative and often radical environmental and agricultural visions.

Puig de la Bellacasa argues that understanding soil as multispecies can entail the creation of new forms of relating based on a community the human is part of (2015). This can also bring forth a rejection of anthropocentric ideas where soil is no longer a mere utilitarian resource for production (2015). Matt seems to hold similar ideas when he considers the lack of interest in soil and people who 'don't really have a relationship, their own relationship with the soil' (Matt, horticulture teacher). He values the possibility of 'getting people to reconnect with each other, with food and with the land' and he hopes that the cooperative 'suggests that there's a different system, there's different ways of living ... encouraging the soil community [laugh]' (Matt, horticulture teacher). His beliefs around the importance of reconnecting with soil are entangled with a rejection of technological interventions in a variety of forms increasingly proposed in agriculture, that he considers 'labour saving devices' around which it is important to ask 'why you are saving the labour'. Instead for Matt 'an efficient way of working is with your hands on mass [laugh]' (Matt, horticulture teacher), once again emphasising the importance of reconnecting people and soil at a grassroots level. For cooperative workers like Matt, who are concerned with re-establishing a relation between the community and food, new innovations are a threat that can widen even further the loss of this connection. This recognised need to return to a closer bond with soil represents a political project towards change in agriculture and society.

Matt's colleague Peter also reflects on the boundaries between human and nature, arguing that technologies can distance humans from the environment with their

efficiency and fast pace. For Peter the connection with the land is about much more than the acquisition of tools and technologies that 'make the job easier'. Growing food is about creating a direct relationship that entails effort and hard work but that allows for a reconnection between land and community. Technology then becomes an element in a broader context of social and environmental relations, a mediation between humans and nature that Peter sees as detrimental in his desire of a more direct proximity with the land.

> Technology it's exactly how humans draw the boundary of the relationship with nature ... we shouldn't just reason in terms of profit, and technology has this risk of just, 'this is going to do it quicker, faster and better, let's do it', and then you just lose a lot of other things that are crucial ... it's not just about using a tool that would make the job easier but it's also about what are we doing here, what's the relationship between us that are working the land and the land and how we're going to change it. (Peter, grower)

The concern about the relationship between people and soil traverses knowledge spaces and emerges strongly among policy experts. Communication officer Kevin is unsettled by what he considers the current missing knowledge and lack of touch with 'real' food that causes people to disconnect from soil. For Kevin there is a need to re-establish a relationship between people and food: 'people buy their food in plastic tubs, they don't even know where food comes from, let alone soil' (Kevin, policy expert), a consideration shared by Jack, who thinks the public 'should know where their food comes from' and 'there's definitely a missing link' (Jack, scientist). There is a sense that mediating elements, such as the plastic wrapped around food and the supermarket, are alongside new technologies the factors that distance people from agricultural fields and determine a loss of knowledge about how food grows.

> You have to actually get people to understand the connection between food and the land ... you've got to make that connection between the food in our supermarkets and then where it comes from. (Kevin, policy expert)

Professor Andrew is also highly concerned about what he considers a loss of knowledge and disconnection from the land. Being disengaged from the land for

Andrew means essentially that people ignore where food comes from and delegate that function to the supermarkets whose packaged food seems to have replaced any bond: 'their engagement with food probably is through things like the supermarket' (Andrew, policy expert). For Andrew supermarkets are 'incredibly powerful players' and they are the emblem of distance, the antithesis of the soil where food grows: 'we're now whatever eight or nine generations removed from the land ... people have lost the connection' (Andrew, policy expert). Andrew's perceived lost connection with food is related to his scepticism towards the use of new technologies, seen as possibly exacerbating the distance. For him, the loss of a relationship with the land also entails a loss of important knowledge that cannot be replaced by new technologies such as hydroponics. Andrew considers these simplistic solutions based on a reductionist, high tech approach. Instead, he argues for a return to the foundation of soil health.

> Why don't we just go back and deal with basic soil health ... people are blinded by science so aquaponics and hydroponics are sold as the new science and people think this is great and then on the other hand they don't understand basic soil science which I suspect is probably not that well communicated by the side of scientists, ... most of us in science areas, our translations is pretty poor ... What is our narrative? And our narrative, I'm often struck we don't know what our narrative is, ... if we as scientists and I include humanities in that, don't make our position and the evidence clear you get these crackpots coming out making all sorts of claims. (Andrew, policy expert)

Andrew considers crackpots (to which he alternates the term 'crank') as a mix of media and 'unqualified people' providing incompetent advice. He acknowledges the clear if detrimental narrative provided by the supermarket industry about 'feeding people', 'keeping prices low' and 'opening up new supermarkets' (Andrew, policy expert). When he asks 'what is our narrative?' he is questioning himself and the academic community more widely that he considers unable to provide a clear and immediate counter-argument against the unstoppable advancement of industry, technology and crackpots. Thus Andrew's mea culpa on the poor communication

skills of scientists among which he counts himself, shows an ability to self-critique and to identify himself with a community of disciplines (I return to the discussion around science communication and translation in the next chapter). But Andrew does have a narrative that emerges particularly strongly when he advocates for re-establishing what he calls a sense of food citizenship that sees food as a public good rather than a commodity.

> I don't think we got a model of food citizenship ... the sense of what I call the greater good has been lost ... Food is just for lots of people just another commodity, it's not a public good, it's not a citizenship issue, it's just, how can I get this as cheaply as possible? (Andrew, policy expert)

For Andrew community growing could be one way to re-propose a model of food citizenship that is lost, meaning a sense of greater good that goes beyond efficient food production and looks at re-establishing a connection with land and food.

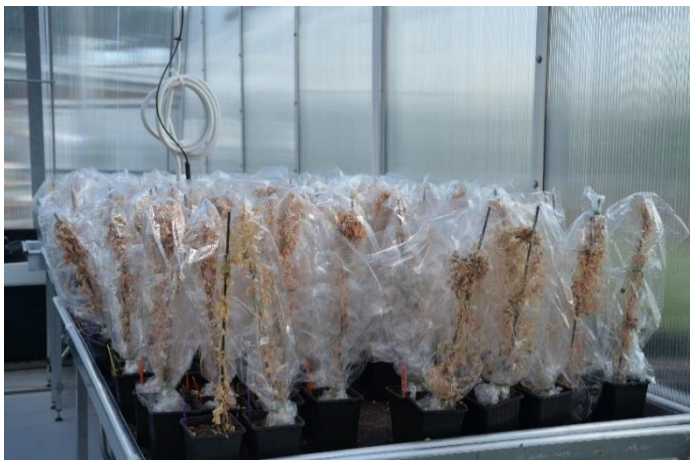

Figure 11: Plants in lab facility

Fiona, a professor of global food and agricultural policy and former leader of nutrition policy at a prominent international organisation, also raises the issue of what becomes lost when certain technologies are implemented. She accepts that they may be efficient and cost-saving, but she explores other costs that are overlooked such as the loss of jobs, environmental damage and more importantly for her, the social damage of losing the relationship with food and cooking and a particular type of connection that she considers only established when eating with others: 'all those technologies need to be weighed carefully on how it affects the environment, how it

affects societies, how it affects livelihoods' (Fiona, policy expert). These reflections are taken further by Naomi, who has been a government advisor on soil health.

> What we really need is solutions that reconnect us with food and not disconnect us ... people just want to look for another thing because the truth is too simple for them or it's not financially effective or it's not new ... we need to grow our food, we need to connect to our food or the people that grow it and we need to pick it and we need to eat it ... and we need to sit around the table and talk and eat and if we are able to do that we probably address some of the main issues. (Naomi, policy expert)

Naomi is concerned about the lack of connection with food that the use of technologies does not address and instead is 'removing us' from the soil (Naomi, policy expert). She believes that some of the solutions to soil health and the food systems are as straightforward as re-engaging with food from its production stages all the way to its consumption around a table, but she is aware that, against the promise of high tech, these 'slower' solutions lack appeal. In order to rebuild this lost relationship, for experts like Naomi concerned with the state of soil and the food system, it is fundamental to 'return to nature' while new technologies are seen as exacerbating this distance. Technological interventions seem to entail a form of trade-off in advantages that are outweighed by the cost of more important elements being lost with their introduction, such as a closer relationship with soil and knowledge around food. Alongside these convictions, there is a clear awareness that technofixes and new interventions hold a stronger and wider appeal in addressing future solutions to agricultural and environmental degradation.

Conclusion

In this chapter I have explored a narrative around time and pace of change that traverses the soil microbiome field, between technoscientific versions of the future and slower approaches to food growing. In the many ways in which science and technology are being leveraged to address urgent agricultural and environmental problems, the microbial life of soil is constituted firstly as a technological intervention

that can tackle a number of challenges in food production currently facing the UK. In the experts' imagining of future solutions, microbial communities living in soil emerge as entities to harness and manage. They are seen as able to provide services, answers and benefits for a food production that needs to move away from the unsustainable use of chemical fertilisers. Across fields of expertise, microbial communities are constituted as short term technological tools through a politics of knowledge production aimed at the control and manipulation of this invisible life. Alongside this promissory and interventionist attitude, the microbiopolitical construction of the microbial object acquires an anthropocentric tinge in the assumption that human needs justify the manipulation and exploitation of other life forms. The expectations around fast pace interventions seem to challenge the possibility to consider more systemic solutions that are portrayed as unrealistic.

The field's orientation to the future however takes ambivalent and contrasting forms when confronted with the presence of a slower attitude focused on long term change. This different pace shows how future solutions are not only envisioned as high tech quick fixes, but also as broader transformations in soil practices. In contrast with technoscientific innovations that are seen as only addressing the symptoms and not the root causes of environmental and agricultural issues, a critical view complicates the soil microbiome arena with the idea that current food production requires systemic long term change and solutions. The suspicion towards technology is also interwoven with concerns over the distant relationship between people and soil and an implicitly constituted idea of nature. Microbial engineering, bioinoculants and other new interventions emerge as possibly in danger of widening this lost connection, thus deteriorating and aggravating even further the dissociation from the natural world and the way food is produced. These more critical positions argue for the need to urgently re-establish a valuable and more direct relationship with land and food that does not need to be mediated by technology. Nature is seen as able to provide solutions if only left undisturbed. In this context, technology comes to represent an artificial tool that causes the loss of authentic relations, knowledge and experiences.

In dealing with the complexity and ambivalence of these differing attitudes among experts and across practice, I have chosen to avoid a categorisation of people and places, looking instead at how these views traverse and constitute the field as interrelated. These variations in perspective cross over sites and institutions within and between communities of practice, from growing sites to policy work, from experimental scientific sites focused on applications to more theoretically oriented establishments centred on knowledge building. The inharmonious and nuanced picture emerged from this lack of linearity cannot be reduced to experts' membership to a field of knowing, nor to a simplistic characterisation that depicts them as blindly embracing and promoting technological fixes. On the contrary, the diversity of positions on the desirable kind and pace of change is grounded in the different ways soil experts imagine versions of the future and agricultural and environmental change. These contrasts ultimately reflect the experts' ethical commitments, worldviews and visionary ideals of the relationship between humans, soil and other organisms, constituting the soil microbiome field as disputed, contested and fragmented.

Chapter 5. Ways of knowing microbial life

Introduction

As discussed in chapter three, knowledge of the microbial communities living in soil is escaping the boundaries of science, to become entangled with growing practices, policy work and public debates. Having considered the future-oriented attitude of the field, this chapter addresses the circulation of soil microbial knowledge across different arenas and the subsequent transformations it sustains in the process of translation from scientific object of study to growing practice and policy recommendation. My aim is to explore the co-production of soil microbial life in these domains and consider the ways in which diverse practices of knowledge-making conceptualise and appropriate the soil microbiome as a multiform entity with both instrumental and intrinsic values. I firstly address how small scale growers know their soil and its microbes in particular ways and how they negotiate their relationship with scientific expertise in the microbial field. A self-awareness around growers' modalities based on sensorial ways of relating such as observation and practice, means that while unable to see microbes, growers are capable of rendering them 'visible' through the senses. In prioritising what they consider a more authentic approach to soil and its life, they are able not only to translate, but to own this knowledge. In this sense, when entering agricultural fields, the microbial communities of soil transform themselves and the growers by affecting their practice.

While soil microbiome knowledge is appropriated and applied in the growing realm, its circulation in policy and public domains presents more friction. A tension is at play when this field of study is rendered into policy recommendations and dissemination to the public. It is evident that soil microbiologists recognise an obligation to share their research findings beyond the laboratory. However, this science does not seem to lend itself to an immediate translation that conveys its relevance. The invisibility of soil and microbes, their lack of charm, the many unknowns of this novel and complex sphere and the association between soil and dirt constitute a hindrance to the field's appeal in the public eye, making the circulation of this knowledge in policy

and public arenas problematic. Oversimplification in this context is at the core of a tension between the need for clear policy indicators and an unfaithful rendering of the microbial world. Soil microbiologists perceive with unease a reduction of the field to its mere policy and instrumental relevance, a translation that denies their sensitivities around the intrinsic value of a neglected area they see as unsuitable to be sold.

Growing with microbes

The emergence of soil from its invisibility can be seen as an event where also gardeners, activists and other non-experts focus on soil by producing knowledge through their practices aimed at reconfiguring life on the planet (Puig de la Bellacasa, 2014). The microbiological event in particular is recognisable in a number of food growing projects I explored during my ethnographic fieldwork, where soil microbiome knowledge enters and circulates in agricultural fields in ambivalent fashion. These small scale growing sites characterise themselves as holding an ethical view of food production as a practice that can be conducted in tune with nature and involving the community in the process. Growers working in these projects stress the importance of experience and observing nature as the most authentic way to know the natural world. While some of the growers show a suspicious attitude towards the scientific project, they often use research findings to confirm their own soil practices, thus asserting the relevance of microbial knowledge in their work. Their ways of 'growing with microbes' in this sense tend to embrace and take ownership of this knowledge as important for their practice. This is because recent developments in soil microbiology confirm that their methods of protecting the soil are useful and valuable.

In a book endorsed by well-known soil microbiologist and soil food web[18] expert Elaine Ingham, gardeners and 'amateur microbiologists' Jeff Lowenfels and Wayne Lewis (2010:5) argue for the need to understand the biological component of soil, to

[18] The ecosystem of soil organisms including bacteria, fungi, earthworms and mice (Ingham and Slaughter, 2004).

garden in a way that takes care of soil microorganisms and to become 'a better steward of the earth' (2010:14). Their *Teaming with Microbes* was first recommended to me by cooperative grower Peter, who described it as 'a classic book' also part of the reading list of the horticulture course taught at the cooperative. Matt, Peter's colleague, teaches principles of soil biology and believes in the value of an embodied way of knowing microbes and soil linked to the senses. He is fascinated by the microbial-induced scent of soil, 'the smell of soil that we are so familiar with', created by the *Streptomyces* bacteria, and that is easy to 'relate to' because 'people can smell it ... they can see it' (Matt, horticulture teacher). Matt keeps at a distance from ways of knowing that become too formal. He rejects the idea that understanding the soil needs to be linked to an academic, scientific or theoretical path: 'you don't need a degree in soil science in order to manage a piece of soil, and then to manage it well as a diverse ecosystem' (Matt, horticulture teacher). This tension and renegotiation between integrating the knowledge of microbial communities and scrutinising authoritative ways of knowing shows an ambivalent relationship with the scientific world.

The importance of a sensorial way of knowing appears evident also at Neil's farm. In over forty years' experience as an organic farmer growing vegetables and fruits, Neil has adopted innovative methods motivated by his ethical beliefs that put him in a minority within the farming industry, such as the rejection of animal inputs like manure that for him would contribute to the exploitation of the livestock industry. Neil considers soil as being at the core of his endeavour and he is keen on understanding the microbial system he works with, that for him involves learning from nature.

> If you work with a biological system and that's what we do, you have to observe nature. ... There's a lot of aspects of soil which you cannot see ... we talk about microbes, bacteria and fungi, but you can see, you can observe earthworms and there's other insects you can observe so we're looking at those insects as an indicator of what's going on in the soil ... it's a very important part of what we do. (Neil, grower)

Neil is aware of the microbes living in soil and he considers visible organisms as indicators of the processes occurring underground. In this way he is able to relate to microbes without the need to see them, an approach shared by communication officer Kevin who considers earthworms as 'a good proxy for soil life' (Kevin, policy expert), directly linking the two life forms so that microbes can show themselves through more visible organisms. While Neil acknowledges the challenge of relating to invisible processes, he is able to know them through seeing more visible lives. Neil aims at encouraging as much microbial activity as possible because he highly values microorganisms in the soil and considers soil 'the most complex of organisms of all on the planet' (Neil, grower).

> There's a whole lot of stuff going on in the soil that I cannot see, and it's quite difficult to understand something you don't see but you know it's having some benefit, it's absolutely essential to the way soil is managed and it's an essential part of the system. ... You need to understand this living material which is beneath our feet, which is so important … the whole of our lives depend on it. (Neil, grower)

As discussed in the previous chapter, while visiting Neil's farm, as well as other growing projects, a number of objects like sowing pots emerged as useful to think about attitudes to biological activity and ways of defining and delimiting the boundaries of microbial life. Neil told me that his pots have never been cleaned or sterilised. This is because he employs intentional defiant politics to encourage biological activity. At the food growing cooperative I visited for six months, sowing pots appear as simply 'messy', thus neither encouraging friendly microbiopolitical encounters nor managing microbial presence. Paxson's microbiopolitics shows how norms and practices of management negotiate the relationship between humans and microorganisms (2013). Practices of cleanliness and dirtiness emerge through these objects across domains, with a laboratory facility used for soil microbiome research displaying immaculate pots and strong regulatory procedures in place to keep 'dirt'[19] at bay. While managing the proliferation of microbes in a lab is clearly

[19] As I show further, the association of soil with dirt is still considered a hindrance to the embrace of soil in the public sphere.

necessary to ensure that the experiments are working, these practices of management demonstrate a cautious behaviour where microbes are seen as in need of strict control. The contrast clean/dirty means that sowing pots do not simply show microbiopolitical norms in place, but are themselves the ways through which these regulations, attitudes and politics are established and put into practice to either discourage or embrace the proliferation of microbial life.

Figure 12: Neil's pots, never been washed

Figure 13: 'Messy' pots at a cooperative

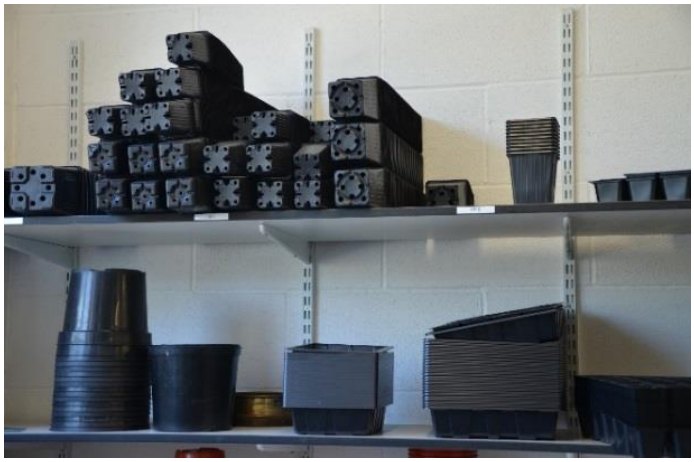

Figure 14: Clean and tidy pots at a UK lab

During the farm visit, Neil showed me the greenhouse where his seeds are sown and then pricked out. When revealing the root system of the courgette plant displayed in Figure 15, an earthworm emerged from the compost much to Neil's pride. This represented for him a visible sign of more hidden biological activity. Neil also considered how conventional farmers would not be as elated by this presence and more generally by the practice of encouraging microbial life. Given the current shift in soil practices that now recognise earthworms as indicators of soil health, with farmers increasingly posing attention to these life forms (Krzywoszynska, 2019a), Neil's opinion of other farmers in this occasion may have been informed by his intention to stand out as a minoritarian steward of the soil ecosystem and thus of microbial life.

Figure 15: This pot contains microbes and earthworms (Neil's farm)

Neil also believes in the importance of collaborating with research centres to investigate the value of organic methods that look after the soil. His farm is currently involved in several projects and trials. In recent years, he has performed a number of soil tests that he shows me on his office computer. Neil embraces the scientific knowledge that he can use and apply to his work, but this does not mean that he submits to the authority of science. The relationship is rather one of validation of what the farmer already knows. The promising soil biology test results confirm for him that his work of forty years in protecting and caring for the soil has paid off. Neil's ethical background could be playing a role in his sense of independence from scientific results that come after and not before his knowledge and practice.

Unlike the farmers studied by Krzywoszynska, who use scientific expertise to justify their practice but mostly do not follow on validating its benefits (2019b), Neil's continuous collaboration with research centres and his soil tests show an intention grounded in practice and verification rather than hypothesis or trust. While Neil does not 'need' scientific validation but uses it to his advantage, his position towards the scientific sphere is not one of discredit either. Neil is active in attending agricultural events and organising workshops aimed at the local community and other growers, where he values the contribution of scientists and researchers he collaborates with. Thus his complex relation with science is located between respect for the expertise and confirmation of his practice based on the knowledge he has acquired over the last forty years.

> [The test] tells what we always suspected but didn't really know for sure, but it tells us that our soil is biologically very active and that's where we need to be really because it is a biological system we're managing so it's very encouraging to know that what we've done over the years has led to a very rich biological soil. ... Our whole system is geared towards soil health so everything is really about looking after the soil. (Neil, grower)

Neil values farmers working together. He believes that farmers have a particular way of knowing through seeing and experiencing in the field. For them, reading a spreadsheet listing soil test results does not clearly translate into practical relevance. The microbiology of soil does not reveal itself to farmers through theoretical trial

results but needs to be translated into a practical language that is about seeing 'for real life' in agricultural fields thus it needs to become a sensorial process that includes sight and physical engagement with soil.

> Farmers are more likely to understand something when they can see it working on a farm, it's more difficult to understand a trial result if you don't actually see it for real life, you can read about it but unless you actually see it in the field it's not so clear, so working with farmers and working with research establishment is very important. (Neil, grower)

Figure 16: Neil holds decomposing woodchip

A small food growing cooperative not far from Neil's farm, discussed in the previous chapter in regard to some of its human-centred attitudes, is particularly focused on soil fertility and does not use fossil fuels or artificial fertilisers. I interviewed growers David and Alex together. Alex tells me that they are 'trying to be a sustainable community living on the land and working it and providing for the local area's needs' (Alex, grower). He believes that 'if more people did it, it could be a real major part of the UK's food production' (Alex, grower). Thus, the cooperative presents itself as a project for social change in food growing. Here, the relationship with the microbial is portrayed as relatively straightforward. David, who holds a degree in physics and keeps himself informed on scientific topics by reading books, is aware of the 'absolutely billions of different organisms and microbes' in the soil (David, grower). He attempts to bridge the knowledge produced in the laboratory with his daily practice of growing by 'reminding' himself about the microbes he cannot see. In this

way, rather than considering invisibility as an obstacle, this microbial feature becomes an awareness.

> Only a microbiologist would really be able to see that with a microscope but, even so if you just remember that and be aware of that ... you just have to keep on reminding yourself really just how complex it is what you're working with. (David, grower)

Thus for David, 'growing with microbes' means knowing their presence regardless of their invisibility and it is through this knowing that useful practices can be implemented accordingly. The cooperative is focused on the abundance of nature and the idea of working with nature, an endeavour David considers 'very simple really [laugh]' (David, grower). David proposes observation as a necessary part of their work inspired by permaculture. He took a permaculture design course that motivated him to start his growing practice and he considers this movement as a way of knowing and developing a relationship with the growing site: 'you have to listen to your soil and see what it's doing' and 'establish a relationship with the land' (David, grower). Listening for him is a way of engaging and staying alert about the processes undergoing in the soil and it is important in becoming closer to the land. David considers observation as the most important skill that can always be improved: 'one of the central principles in permaculture is observation ... Just observe and improve your observation techniques; that is always something you can work on' (David, grower). David seems to interpret the skill of observation as 'common sense' and a 'practical approach' (David, grower). His language around experiencing through the senses and in particular observing and listening, stresses the importance he places on the body in relating to the land. To listen, to observe and to improve oneself in these embodied practices means to pay attention and develop a meaningful connection with soil and food growing.

David does not consider himself 'a very experienced grower, I'm more of a scientist' (David, grower). In this context, being a 'scientist' represents an identification with a model David considers accurate rather than entailing the employment of specific scientific measurements. By 'scientific approach' David implies trusting the science and discovering for instance that artificial fertilisers 'are actually dependent on gas'

(David, grower). Science and permaculture principles for David evolve alongside each other in his intention to 'help the planet' and disrupt what he considers detrimental intensive agricultural practices. David's position is thus complicated by a value for both credentialised scientific expertise and experiential knowledge.

> Sometimes it might help to record things, I don't tend to do that too much, maybe I found education was a bit too formal and it's kind of made me go the other way but ... you just have to have your wits about you [laugh] and be passionate also about what you do and believe in what you do. (David, grower)

In promoting the concept of 'passion', David aligns his growing ethics to a discourse around enthusiasm in the workplace. While he claims to adopt a scientific approach, he has distanced himself from scientific formal education and this locates him in an ambivalent position between an appreciation of science and the rejection of its formal ways of acquiring, producing and disseminating knowledge. This uneasiness around formal science can be recognised also in his description of the cooperative, where they 'had to form a cooperative structure and get a bank account and fill out lots of forms and things' (David, grower). Pointing out the necessity for a structure and administrative tasks, David shows a discomfort around having to be related to a bureaucratic system he would like to reject.

To negotiate the tension between formal pathways of knowing and experiential practice, David proposes that 'you need to kind of take these ideas and ideals and ... bear them in mind but you also have to practice different methods and learn for yourself' (David, grower). Alex also reflects on the balance between science and practice, stating that 'it can take time to translate the science into processes and techniques that actually work in the field', thus the transition from science to growing takes some adjustments. Science can work in theory for these growers but it then needs to be adapted to the characteristics of the growing site where experience acquires an equal value: 'you need experience plus the knowledge to be able to put things into practice' (Alex, grower).

David and Alex also show a concern for the current state of politics around soil. David considers the lack of involvement of scientists in parliament: 'it's an absolute travesty really that we're so underrepresented in the House of Commons' (David, grower). Alex goes even further by seriously advocating a 'Ministry of Permaculture that actually looks at the UK, our long term food needs' (Alex, grower). While David and Alex may be conflating scientific advisors with elected representatives, their argument around the importance of evidence-based policy in agriculture finds alliances across more recognised forms of competence, joining early career researcher Rachel in her concern for the lack of expertise in government.

> There's just not many scientists in the government. ... it is a bit not worrying but kind of worrying ... I assume they maybe have scientific advisors hopefully to pass messages on and things but whether it's actually evidence-based kind of policy I don't know. (Rachel, scientist)

During my visit to the cooperative I had the impression that David was not instrumental in the food production and delivery side, leaving others to deal with these practical aspects: 'you could call my approach quite experimental but there's people here who have much more productive ways of farming as well' (David, grower). When David explains his practical application of permaculture, food production takes a secondary position to proposing 'alternative ways apart from industrial agriculture' (David, grower) and is seen as a long term result. Alex attempts to reduce this possible tension between experimenting and producing food by underlying the importance of using methods that are known to work: 'I put more effort into the tried and tested things that I know are going to pay off, cause we need to make a living' (Alex, grower).

For grower Alice, this point represents a problematic ambiguity between embracing experimental ideals and the practice of growing food. She considers permaculture's low levels of food production as not necessarily affordable for those who depend on the land for a living. Alice works at an urban farm that provides food to local restaurants as well as animal entertainment to the public. In Alice's words, the farm's remit is giving the public a chance to see animals 'they would never get to see normally in a city ... on some level it is just a nice place for people to come and visit

without learning anything, hopefully they do learn' (Alice, grower). The growing aspect is not politicised at her site in the way it is at David's cooperative. Even so, Alice seems to be more grounded in the importance to grow food and to represent an example of what can be achievable in a city.

> In a perfect world we'll be able to do a lot more of that, in the meantime we've actually got to produce food, ... we do have to keep our yields quite high and I think it's important that we demonstrate that we can do that. ... we're trying to demonstrate that organic growing is the hope. (Alice, grower)

For Alice, permaculture is admirable from an ethical standpoint, but even more vital is to show that organic growing is the 'hope' that can provide solutions for the future of food production. Thus, the future emerged here is formulated as a hope not yet possible to envision because it requires a change towards practices that Alice still considers minoritarian. Many of the permaculture practices are already implemented at her city farm but what is critical for her is to show that even small urban spaces can produce organic local food in ways that take care of the soil and promote biodiversity. Thus her critique against low food production comes from a drive to show an alternative to intensive agricultural practices that is able to connect food production to biodiversity.

> I just know that we need to have good soil ... I have a very sort of practical approach to it rather than a sort of more scientific approach, so I have to say I don't spend a lot of time looking up information ... but I do put that knowledge into practice because that's what I do every day at the farm. (Alice, grower)

For Alice the scientific approach is a science-based attitude rather than a particular method to know the world. Although she is aware and interested in soil microbiome research, she is 'a bit short of time' (Alice, grower) and seems to feel guilty for not knowing enough. In this sense, knowing about microbial life, although important, is not crucial for her daily growing practices that need to come first and she is comfortable with letting microbes work without her understanding. There is therefore a theme running through that dichotomises scientific knowledge and

practical experience, where the latter is considered by Alice and other growers interviewed as more valuable, useful and authentic than mere theoretical knowledge acquired through formal education.

A large sign at the entrance of the main building of the worker cooperative where I volunteered and observed for six months, states 'Earth Care, People Care, Fair Shares', thus declaring its adherence to the permaculture ethics. This food growing project can be defined as practicing what Puig de la Bellacasa calls alter-biopolitics, practices of ecological collective care aware of the 'webs of relationality' and the interdependency of life (2010:167). Here attitudes towards microbes emerge through practices such as feeding the soil by adding organic matter to preserve its life. The relationship with science however is as complicated as in the sites explored above. The tension materialises particularly in a continuous boundary work around what constitutes good scientific knowledge. On the one hand, strong ethical principles around soil and food systems seem to reject lab-based science, on the other, soil microbiology is considered a relevant field, as long as it is appropriated and rendered an ethical project. Peter, a grower already mentioned here and in the previous chapter, offers an instance of the ambivalence, complexity and compromise involved in the attempt to 'grow with microbes' and deal with scientific expertise, in a continuous shift of position around worthy ways of knowing the soil and its life. Peter links the necessity to observe and understand nature to the rejection of a lab-based knowledge that he sees as detached from the soil.

> Growing in a sustainable way also means using what nature is telling you, is teaching you, using it at your own benefit, so trying not to disrupt what nature would do ... observing nature yeah, definitely, that's why I don't trust people who have been studying in the lab and haven't looked at what really happens in a complex system like a farm or a permaculture site. (Peter, grower)

In Peter's account, the narrative around 'working with nature' is strongly dissociated from a scientific approach. Nature is seen as a realm where no disruption should occur, thus not considering that growing food 'using what nature is telling you' still entails a level of intervention even when this aims at mimicking rather than 'going against' nature. Like David, Peter believes that observation allows him to decipher

the message each plant is sending: 'what is this plant trying to tell me?' (Peter, grower). Understanding the message from nature means for him to accept also when a particular plant is not growing well, thus not forcing the conditions through inputs and interventions. This is how observation can become a way of knowing that allows for respecting each plant's levels of adaptability, showing a particular form of relating to the nonhuman as an entity worthy of being 'listened to' and respected. Peter also specifically points to a perceived unbridgeable distance between research centres and agricultural sites, thus a distance from soil. As will become clear, this distance is epistemological rather than literal, in a dichotomy between distance and proximity that Peter slowly constructs. Touch is what makes a relationship with soil worthy, unlike laboratory soil that is not truly touched.

> I personally don't trust too much the knowledge and the inputs of people that have never touched the soil ... it's coming from a place that it's pretty far away from the end product, the soil and the plant. ... I think reverting to local is the way to go. (Peter, grower)

In a dismissal of those in the lab who do not touch the soil, touch becomes authenticity, an 'immediacy as authentic connection to the real' (Puig de la Bellacasa, 2009:307-308). This element is also recognisable when invoked by growers, scientists and policy experts who see technological solutions to food production as removing people from the soil, as discussed in the previous chapter. However Peter presents also a distance of another order. While he advocates for 'touch' as entailing an authentic embodied relation with soil, he also stresses the importance of not intervening and let the soil do its work. Closeness to soil and the land means therefore also trusting the independent activities of nature and avoiding interference. Authentic touch then includes lack of touch and proximity involves an attentive distance from what is most precious, a respectful restraint adopted for the sake of soil as well as for improved growing results.

Peter points to the assumed lack of physical contact between the scientist and the soil, a distance further dramatised by the physical distance between the research institution and the agricultural field, implying that if the research centres were closer to the agricultural sites then they would be more trustworthy. Scientific distance

therefore is problematic because only by touching it the soil can be really 'known', but Peter uses the idea of distance as a metaphor for the displaced relation of the scientific project with soil. Thus, I argue that the distance he refers to is epistemological rather than geographical, related to different ways of knowing the soil that hold unequal purpose and value. Soil itself then carries different values according to its use. As long as it is employed to grow food for the community, to increase biodiversity and to create a local and seasonal food system, it is a valuable soil. When used for scientific research, none of these elements are present, according to Peter, and scientists' relationship with soil lacks an authentic connection. In this way, the site of science and the site of soil emerge as two separate spheres and by arguing for a localised science, Peter attempts to shorten the distance.

In some way nuancing this problem of distance, during the interview Peter also proposes a milder position that concedes those 'in a lab' may hold 'an angle that the farmer doesn't have' (Peter, grower), therefore suggesting that the two spheres are both worthy (and of equal value). The concession seems to imply that knowledge that emerges without touching the soil can after all be worthwhile. This ambivalent position continues further when Peter considers the years spent on scientific training that for him seem to deserve respect. However soon after, Peter goes back to the initial scepticism, pointing once again to the problem of distance and dismissing the epistemological worth of science in favour of that of agriculture, by relegating theory to a lower position compared to the farmer's embodied practice in the field. Peter also conflates science and technology when he sees scientific research as not different from technological interventions in agriculture.

It is then possible to say that Peter's assumption that research sites are irremediably distant from the soil may be related to an idea of science purely carried out in the sterile environment of a lab by a scientist in white coat. He does not consider that many research sites, including ones I have visited, are extremely close to farms and fields where scientists do touch the soil and grow plants. Some of the soil microbiologists interviewed in fact stress the importance of field work and a willingness to stay close to what they consider the 'real' natural environment.

Microbiologist Nicholas in particular regards field work and the study of the 'real world' as invaluable and the only way to understand nature.

> I'm more comfortable with field-based work, so we go out in the natural environment and we study it, because I think when you bring things back from the real world into the lab you lose relevance and you lose scale and those can mean it's very difficult to extrapolate lab results back into the field. ... the best way of understanding nature is to go out and study it in situ. (Nicholas, scientist)

Figure 17: Laboratory: a space Peter considers distant from soil

Peter's ambivalence is complicated even further by the presence of a microscope at the cooperative, used in the horticulture course the cooperative provides, which includes a soil science unit. When it comes to the microbial communities living in soil, the narrative about science seems to change. Peter is aware of microbes, 'little things that eat each other all the time' (Peter, grower). This 'knowing' of microbial presence is both embodied in the act of turning compost and subconscious in the awareness that underlies his daily work with soil.

> It's at the back of my mind … I just know … when I turn compost, I know almost subconsciously that that's the product of these things munching on each other … I don't remember it suddenly, it's just at the back of my mind all the time. (Peter, grower)

Peter, who only moments before presented suspicion and concerns for the scientific endeavour, now complains that traditional farmers do not have enough knowledge of the microbes living in soil. Like Neil, Peter refers to conventional farmers to which he opposes himself as a minoritarian member of the growing community.

> People who work in this field, but in a conventional manner, don't have a clue of the soil life, of the different microbes eating other microbes and that's releasing nutrients, they have no idea. ... I think it should be crucial to whatever you do, what kind of microbes you're feeding and what's going on there. (Peter, grower)

The fact that this knowledge comes from institutions not always closely located to agricultural sites and from scientists in a lab who may only touch the soil when collecting samples is not seen as a problem on this occasion. The microbial life of soil is considered worthy by Peter only when it is co-created on site, suggesting that the problem in his relationship with science does not necessarily lie on the content but on the aim of the research. The distance of scientists and research institutions from the soil can then be seen as a proxy for a more implicit and different kind of distance, from what Peter considers ethical motivations for doing scientific research. Because he sees the research on the microbial communities of soil a 'just' and useful endeavour that meets his own environmental sensitivity around the importance of soil life, the distance previously considered problematic is no longer an issue. The distrust dissipates because the soil microbiome is appropriated, reproduced and rendered valuable at the growing site by people who are close to the soil.

Thus it is in the translation, the 'rendering from one language into another' (Merriam-Webster, 2020) within the soil space that microbial expertise becomes worthy, valuable and transformative, in a process where this body of knowledge is co-created to reach beyond the initial field of production. The etymology of the word 'translation' also involves a relocation, 'a movement from one place to another; the transplanting of a sapling;' (Middle English Compendium, 2018); the 'removal of a saint's body or relics to a new place' and the 'carrying across, removal, transporting' (Online Etymology Dictionary, 2020). Thus translation refers to the physical carrying of one thing - a relic, a young plant - from one place to another. It is this relocation,

the transplanting of microbial knowledge from the lab to the field, that entails the transformation of this object emerged in the growers' account. It is in the 'move' that microbial communities become something different to what they were in their site of origin. Similar to the ways in which the soil test constitutes a self-validation of Neil's work with soil, research on the soil microbiome circulates, is acquired, used and ultimately owned by the cooperative to promote the views and ideals the food growing project holds as valuable. This is how microbial knowledge enters and circulates across agricultural fields, is transformed in the process of translation and in turn changes the way growers see their soil, touching and affecting them in profound ways.

The intrinsic value placed on soil and microbes in these growing projects overturns an understanding of knowledge exchange often conceived in the form of unilateral delivery of expertise from academics to growers and not the other way around. These relationships provide the 'multi-way exchange' advocated for instance by the Research Councils UK in the document 'Impact through knowledge exchange: RCUK position and expectations' (2014). The document recognises the importance to 'facilitate the multi-way exchange of knowledge between academia and research users in business, public and the third sectors' thus potentially including growers (2014:2). Neil offers some instances of these multi-way collaborations with research centres while Peter's cooperative shows how the circulation of soil microbiome knowledge does not entail a submission to the scientific project but an appropriation of this field of study, put into use at the growing site.

Furthermore, both growers offer an instance of the constructivist possibilities available in the encounter with another species, as proposed by Stengers (2010a; 2010b). Even when these emerge only briefly in the recognition that microbial communities are beneficial to the soil, Neil and Peter allow for novel relationalities with another life form by paying attention to it. Similarly, Alice's assertion of the importance of representing a working example of ethical, organic food growing rather than focusing on the scientific knowledge of microbes, shows how the encounter with another species can take the form of an embodied whisper that comes to the surface, it is said and now heard as a praxis that affirms the possible. In

detecting this coming to matter in the moment it emerges, in the conversations with these growers, it is possible to consider that new becomings with another species are reflected and materialised in food growing practices that assert the liveliness of soil.

Finally, drawing on Krzywoszynska's call for caring as a systemic project, land use and the future of soil cannot be conceived as arenas relegated to the effort of farmers alone (2019a). I also argue that this systemic endeavour needs to begin with the recognition that growers' direct, sensorial knowledge of soil ecosystems matters as an expertise in itself. While their competence may still not be recognised or valued as credentialised, their knowledge represents an expertise of practices acquired through experience grounded in the senses that is then shared with the wider community. A bidirectional dialogue where farmers also inform scientists could then be achieved when the actors involved are able and willing to talk to each other and think with each other. When scientific and growing expertise meet, they can prioritise the environmental aspects of soil microbial communities that some of the experts across areas of competence hold as important.

Granular knowledge

In the relations explored in the previous section, the circulation of microbial knowledge from science to growing practice is mediated by a concern over an epistemological distance from soil and modes of knowing considered dubious in the way they value soil. Here I examine how the translation of soil microbiome knowledge in policy discourse is associated with a tension around oversimplification and a loss of granular complexity. There is a sense that when the microbial entity enters the policy domain, its translation causes more friction than when traversing the growing space. This can be explained by the expertise around soil that growers already hold, as noted by Caroline, an ecologist with experience in science communication, who considers even gardeners 'a sector of the public that you can communicate with quite well' (Caroline, scientist). Soil microbiologists are not as involved in converting their knowledge across the growing field as they are when translating it into policy discourse. It is in this arena that they become acutely aware of the reduction of their complex knowledge to an approximate language suitable for

a non-expert context. Soil microbiologists recognise the duty to respond to an increasing policy concern around soil and its ecosystems that entails the urgency for clear indicators on soil health and degradation. However when they attempt to translate their field of study into policy recommendations, they perceive a pressure to reduce their knowledge to a point that risks losing accuracy. They see the adaptation of this novel research area into straightforward policy recommendations as possibly resulting in distortion and loss of complexity.

From the analysis of policy documents, the nature of policy requirements emerges as focused on clarity and tangible guidance that do not allow for an attention to nuances and details. The policy requisite to represent and speak for microbial knowledge creates an unresolved tension with scientists who are attempting to disentangle a complicated object of study. More deeply, this friction interrogates the intrinsic value of knowledge (and of soil and its ecosystems) as opposed to its instrumental worth. When the significance of soil microbial life is understood merely in policy terms, with a discourse around 'unlocking' its potential, as shown in the report analysed in the previous chapter (Microbiology Society, 2017), its intrinsic value becomes neglected.

Lisa, whose background involves academic research on policy as well as parliamentary research, is director of research strategy and policy at a large university and is involved in a number of projects across different scientific areas and their engagement with policy. While not working with soil in particular, her contribution is helpful here in understanding the translation of scientific knowledge into policy priorities in a wider context[20]. For Lisa, translation is the process that allows science to inform and become policy, but it is not necessarily part of the academic skillset. In a way justifying the necessity and importance of her work, she sees external intermediaries as taking the pressure off academics by facilitating links and relationships and translating inaccessible and technical scientific knowledge into clear policy recommendations. For Lisa knowledge translation is fundamental in informing policy: 'it's really important to get expertise into policy so policy is as strong

[20] I interviewed Lisa precisely to gain insights into the process and challenges of translating 'granular' scientific knowledge into public policy.

as it can be' and when this does not happen policy is 'misguided at best and wrong and damaging at worst' (Lisa, policy expert). She refers to 'locked away' expertise and 'very dense technical articles' thus critiquing what she considers the problematic inaccessibility of academic research and arguing that, despite the challenges, policy engagement remains a duty for academics. Lisa does not argue for each individual researcher to engage with policy makers but she defends the need for universities to be in touch with their community as a moral obligation to involve social groups that may be affected by the research. Lisa believes in the intrinsic value of knowledge, but she extends this value to include policy improvements and engagement especially when science is publicly funded. By arguing for society and not just a few academics to benefit from expert knowledge, Lisa considers knowledge as fundamental for its own sake and this includes dissemination that can illuminate society.

> What's the point of generating knowledge that never illuminates anything? ... I'm absolutely committed to the idea of the pursuit of knowledge for its own sake but actually to me part of its own sake is illuminating our understanding of the world and that's not about illuminating two people's understanding of the world. (Lisa, policy expert)

Lisa views translation as a straightforward transition from scientific evidence to policy recommendations. Her position however is complicated by a lack of agreement around the role of evidence in policy making among experts. Professor of global food and agricultural policy Fiona argues that 'sometimes [policy making] can be evidence baseless' (Fiona, policy expert) and Andrew, professor of food and health policy, lacks confidence in the use of evidence in parliament where 'vested interests' from powerful stakeholders have more relevance than expert recommendations (Andrew, policy expert). Despite these ambivalences around the role of evidence in policy making, communication officer Kevin, like Lisa, asserts the obligation for scientists to translate their research. He has what he defines an 'unusual background' including academic research and a business that has provided him with an expertise of 'customer service' and 'user needs' (Kevin, policy expert). Kevin experiences a level of frustration around what he considers scientists' unwillingness to simplify their

work so that it can inform policy. His own experiential knowledge has taught him the bullet point language of governmental policy.

> When you're dealing with governmental agencies what they want is a briefing document, and it's got to be three bullet points, just very, very simple, and it's making sure that the scientists understand that as well, that their science is going to be reduced to that and if they're not happy with that then it's not going to get into policy. (Kevin, policy expert)

What Kevin considers a reduction of science and the loss of nuances however, for the scientists involved may represent fundamental aspects of their research. Translating knowledge around the microbial communities of soil, rather than the loyal rendering from one language to another that Kevin and Lisa seem to portray, for soil microbiologists leave important meanings and concepts behind. These concepts and meanings constitute the main drive and motivation of many soil microbiologists I interviewed. As a point of contact between science and policy however, Kevin does not accept that scientific modes of knowing, understanding and delivering knowledge, may diverge from policy requirements to the point of resulting in incompatibility.

> Some nuances will be lost and that's what scientists don't like, scientists like very, very granular 'I think this might be the case', you know, blah blah blah. ... I get frustrated with that occasionally. (Kevin, policy expert)

Kevin seems to enjoy picking on scientists' perpetual disagreement but this is because he truly believes in the application of research, meaning that when research has no impact 'you might as well not have done the research almost' (Kevin, policy expert). At one point in the interview, Kevin realises he is saying 'I think' too often and jokes 'I've been around scientists for too long I started saying "I think" all the time', showing his frustration with what he perceives the continuous vagueness of scientists (Kevin, policy expert). His perspective has changed since the days when he was doing a postdoc in biochemistry. When the younger Kevin used to protest against the application of his work he was rejecting the stain of applied research whilst elevating the purity of 'proper research' carried out for its intrinsic value.

> I'll put my hand up ... someone said how is your research going to be applied and I said 'I don't know, I don't care, clinicians do that research, I do proper research'. (Kevin, policy expert)

As already discussed, research on the soil microbiome is primarily aimed at soil restoration in light of agricultural and environmental destruction and it therefore entails the need for policy translation and public awareness. However, these discussions highlight the problems and challenges of implementing this process. The policy need for assertion and answers clashes with a field that is perceived by its researchers as too complicated to simplify. Soil microbiologists consider microbial communities as a remarkably intricate object of study: 'they're incredibly complex communities' (Nicholas, scientist) and 'a complicated area to explain because it's involved in so many processes' (Karen, scientist) where 'we understand very little for now' (Joseph, scientist). Because of the ample space between the many unknowns of the field and the need for clear policy indicators, when considering the problem of translation I draw on Natasha Myers' concept of rendering as performative representation (2015). Myers' crystallographers attempt the representation of invisible molecular phenomena through models created 'to *render* the molecular world visible, tangible, and workable' (2015:18). I consider these representations as an exemplar of the translation of the soil microbiome from invisible to visible and 'workable' for policy makers. In the same way that protein models can be seen as a 'fabrication' (2015:19), so too the rendering of microbial life in policy can be understood as an inaccurate adaptation often prone to misunderstandings. The translation of soil microbiome knowledge is performative in the sense that it intervenes, it is a representation that is 'made' and enacted to shorten the distance 'between the representation and its referent' (2015:19). In this sense, the premature efforts to represent and define 'the many silent actors of the social and natural worlds' constitute a process of both displacement and representation (Callon, 2007:75). Far from being a mere description, in the translation and search for an agreed version of the processes occurring underground among silent microbial communities, concepts and complexities become displaced and out of context.

An instance of this conflicting dynamic presented itself starkly when discussing the definition of 'soil health' with experts across fields of expertise. As shown in the previous chapter, addressing soil health is becoming a government environmental and agricultural priority. However, among soil microbiologists, soil health remains a complicated concept. The novelty of the field, with its uncertainties and unknowns, mean that the study of soil microbial communities is still unsuitable for immediate translation in terms of defining a healthy soil. A general idea of soil health, requested by policy experts, does not reflect the many ways in which soil is conceptualised by microbiologists. Jack, a molecular microbiologist, observes that 'soil health seems to be the vogue at the moment. ... and that's in a way a difficulty' (Jack, scientist). This is because 'a healthy soil is dependent on what you are trying to grow in that system, so you can't have a generalist idea of what a healthy soil is' (Jack, scientist). The policy need for indicators of soil health represents for him a burden: 'we're all meant to be coming up with indicators of a healthy soil and I think those indicators are going to have to be quite broad, some of them very simplistic' (Jack, scientist). While Jack objects to a generalised concept of soil health, he employs it when telling me about the 'effect of agronomy practices on bacteria population and whether that affects our soil health and their health' (Jack, scientist), thus showing how a complicated concept in strictly scientific terms, can be useful in the communication with the public or other non-experts.

The direct relationship Jack traces between soil health and specific crops is unlikely to be embraced by ecologically sensitive growers like Neil, who considers soil health the element that constitutes a resilient system and would rather connect the idea of health to a biologically active soil. This is because for him soil is not uniquely a growing medium, but an element with wider values, regardless of its capacity to produce good crops. But aside from growers, also plant and soil microbiologist Ben considers how a healthy soil in terms of good yield could be 'a disaster' from an environmental standpoint, thus his frustration: 'what does that mean, healthy in terms of what?' (Ben, scientist). Similarly, molecular biologist Julia points out how confusing the concept can be, arguing that the quality of crops should not determine its definition: 'I don't know what a healthy soil is now, I guess we shouldn't really

measure it by how well it grows crops because that's not quite right' (Julia, scientist). Thus, reducing the concept of soil health to the capacity of producing high yield is not necessarily agreed upon. The 'Soil Health' report, analysed in the previous chapter, seems to acknowledge the complexity of the concept highlighted by these microbiologists, as 'context dependent': 'soil health is multi-faceted, depending on a range of biological, chemical and physical factors' (House of Commons Environmental Audit Committee, 2006:6).

However Kevin is clearly pleased in the belief that his programme has contributed to put soil health 'on the agenda' in the policy arena (Kevin, policy expert). At the same time, he is dissatisfied with the ambiguity of the concept that becomes used interchangeably with soil quality also by scientists, to the point of becoming meaningless. For him, it is necessary to have 'a reasonably hard definition' of what 'makes a healthy soil' or what 'doesn't and until then, there's always going to be confusion' (Kevin, policy expert). Kevin's frustration about the 'burning issue' of 'how to define a set of indicators for soil health' is related to what he considers scientists' detrimental attitude and unwillingness to agree on basic definitions. This is because, as already mentioned, Kevin believes that scientists waste much of their time in debate and disagreement: 'scientists don't like agreeing on things anyway, they like that kind of coffee debate, endless debate let's talk about things' (Kevin, policy expert). Bypassing the recognised complexity of defining a healthy soil, Kevin argues for clear indicators that are agreed upon, portraying arguments around the nuances of the concept suggested by microbiologists like Jack, Julia and Ben as problematic attitudes that obstruct his work. It is in this way that their concepts, concerns and definitions are displaced in the attempt to reach a fabricated representation. This controversy epitomises an instance where the need for policy translation conflicts with the difficulty to reduce complex processes to straightforward recommendations. It also demonstrates the contentious nature and unresolvable 'messiness' of the soil space, where listening to experts across different sites conveys the multiplicity of an object of study assuming diverse forms and meaning across fields. These ambivalences and contested definitions contribute to the challenge of knowledge translation.

One of the elements at the core of this tension is the pressure soil microbiologists sense in 'selling' their work in a way that entails the erasure of important details. While concerns around the distortion of science are arguably not limited to the field of soil microbiology and are widespread among scientists (Sismondo, 2004), those studying the microbial communities of soil are particularly under pressure because of their sensitivities around the intrinsic value of a neglected field they see as unsuitable to be sold. Chris, a molecular microbial ecologist, bluntly argues that policy makers are only after a clear message to sell.

> It can be quite dangerous to get preachy about things which we know are inherently a lot more complicated than simple messages which our press officers [laugh] are always trying to get us to sell. (Chris, scientist)

Chris' use of business-related concepts shows he is keen to distance himself from policy specialists and from the unfaithful rendering of his work. He builds an image of policy makers as sales people in need of a quick turnover, a cynical body of regulators only interested in reducing the soil microbiome to a sale transaction with anthropocentric purposes. He considers the natural capital framework[21], employed in policy to communicate the value of the natural world, as concentrating only on services and therefore neglecting the intrinsic value of biodiversity.

> They want to know what's the benefit to biodiversity which you can sell, it's this all natural capital framework ... you could sell biodiversity if it brings in tourists and people, it contributes to people's health and wellbeing ... Do they care about the microbiome, yeah I'm sure they say they care but, ... it's always been quite hard to get them specifically to fund because they just deem it as a new science, what policy change are they going to implement as a result? (Chris, scientist)

Chris finds it problematic to provide the 'hard facts' policy makers are after about 'what can be directly relevant' (Chris, scientist) because benefits such as biodiversity are not easy to communicate and sell. He links the lack of immediate change that can

[21] Defined as 'an extension of the economic notion of capital (manufactured means of production) to environmental "goods and services"' (European Environment Agency, 2020).

be implemented while this field is in its initial stages with the difficulty of getting funded. Thus the problem of complexity does not only result in a challenging relationship with the policy sphere but has more serious funding implications for the scientists working in this field. Related to this, Chris finds an issue in auditing the impact of change in soil because of its slow pace, thus referring to the longer time scale of soil and microbes for which policy makers do not have time to wait: 'for soil you might not see [an impact] for twenty years' (Chris, scientist). In this sense, he points to a temporality imbalance where the slow process of soil formation and the complexity of its invisible ecosystems are antithetical to the need for simple and immediate policy recommendations. For Chris, this asymmetry can result in funding issues, a concern also raised by agricultural microbiologist Margaret who argues that the importance of soil needs to be promoted, otherwise funders will wonder 'why are we studying soil, it's just like earth' (Margaret, scientist). One of the risks of considering policy requirements a priority is that 'you try to find some kind of spectacular results or you do something that you know that it will work' (Owen, scientist), thus having negative implications on the type and quality of research.

The pressure for application is also identifiable in the trend towards the creation of products, as noted by Jack, a microbiologist who believes in the importance of doing 'basic knowledge building' and 'instil an overall knowledge' because 'you can't have an end product without knowledge' (Jack, scientist). Jack therefore acknowledges the role of the market in driving this research and its inevitable solution-based dynamics, a role underlined also by Daniel, a policy manager at a microbiology institution, when discussing industry's interest in the soil microbiome: 'in soil particularly there seems to be quite a big drive in looking at biologicals to deliver more sustainable farming' (Daniel, policy officer). These concerns around the way research is moving towards the need to sell, either a product or a policy guidance, show how soil microbiome knowledge is at the intersection of multiple tensions that these microbiologists see as threatening its very existence as an intrinsically valuable field.

Furthermore, some of the microbiologists interviewed find 'pitching the science' challenging in choosing the aspects of research that may be of interest: 'I actually find it fairly difficult to translate research into policy, I'm not sure which of these bits

that we found is important' (Julia, scientist). This uncertainty around expectations is evident also in the degree of humbleness among scientists that may play a role in their reticence in getting involved with policy engagement. I identify here a sense of 'epistemic modesty' as highlighted by Martyn Pickersgill when discussing how, among epigeneticists, a moderate approach to scientific progress and a willingness to admit uncertainty and lack of consensus, constitute a strategy to convey professionalism and scientific responsibility (2016). Epistemic 'ostentatiousness' on the contrary, is an attitude considered less acceptable among scientists in that it tends to show only the successful side of scientific research.

Along with the capacity to admit when things are not well understood in the field, the microbiologists I interviewed are humble and uncertain specifically around the extent of their contribution, the impact of their work and the possibility to provide recommendations. Their reluctance is related once again to the non-immediate translation of their work into actual practices and implementations, thus 'it's more kind of adding to knowledge of the rhizosphere' but as for recommendations 'it's just so complex ... there's just so many variables' (Emily, scientist). Rachel hopes to 'at least make a small dent in the gap knowledge' and 'if I find anything I'll be happy really [laugh]' (Rachel, scientist). The possible outcomes of her project will be limited to contributing to existing knowledge so that other researchers may introduce new practices because of her findings. Bioinformatician Anthony also expresses concerns around some data he has collected and he is now hesitant to start analysing because there may be nothing to find: 'I'm really scared to look at it because I don't think there'll be much in it [laugh] ... there's always this chance that I will not get anything out of it, yeah it's science really' (Anthony, scientist). Anthony's conclusion shows a willingness to accept the limits of his work as part of the workings of science, a practice that entails the possibility of getting it wrong.

Overall, there is a sense that a careful navigation is needed when approaching the process of translation, with even relatively senior scientists convinced that a dialogue with policy makers has to happen 'at the director level rather than at the scientist level' (Ben, scientist). Despite this, soil microbiologists accept the duty to translate their knowledge as an obligation, given the public funding involved in this scientific

field: ‘we take money from the government’ so ‘we have commitments to feeding the policy agenda’ (Chris, scientist). In terms of public dissemination of soil microbiome science, to which I now turn, this sense of obligation, as well as the problematic displacement of concepts and meanings involved in the process of translation, present themselves with equal force.

It’s not pretty flowers

In the last twenty years in the UK there has been a strong move towards addressing the relationship between scientific expertise and publics (McNeil, 2013). This has led to numerous initiatives and programmes aimed at increasing public engagement with science. In the soil microbiome domain, a stress on involving publics through events and talks that highlight the importance of the living soil emerges as an imperative for microbiologists. When addressing publics however, the problem of invisibility of the soil field and its lack of appeal emerge even more strongly than in policy discourse as a hindrance to capturing people’s imagination. If scientists are once again convinced of the necessity to simplify their research and ‘share’ their expertise with publics for the sake of securing support for their science and therefore for public funding, they seem destined to encounter disappointment and frustration when met with an uninterested audience unable to fully engage with a rather specific and still invisible field. Oversimplification, used as a strategy to overcome the neglect of the soil microbial communities and to intrigue the public with simple facts around soil life, entails a reduction of expertise in favour of a more empathic approach aimed at understanding those who do not share an enthusiasm for science, thus avoiding to overwhelm them with complex knowledge.

A particular instance of the ambivalence of public engagement was provided by Anthony, a bioinformatician involved in a number of studies on microbial communities in soil and other environments. Anthony co-authored a paper on mycorrhizal fungal communities growing across different forests. In the paper, published in a prestigious journal, ‘one of the conclusion is that it’s the pollution that drives soil fungi’ (Anthony, scientist). To Anthony’s surprise, the paper was popularised by ‘the journalists’ through an emphasis on pollution as the only relevant

aspect, despite the number of elements the paper examines. Anthony regards this interpretation as related to the need to simplify an otherwise inaccessible and technical article that could not possibly capture the public's attention. Although he is non-judgemental in recounting how the press reduced the entire paper to a question of pollution, he considers this a 'eureka moment' that taught him some important lessons in terms of the tendency of the press to focus on 'something that's controversial' and the challenge of providing the public with an accurate translation of complex data and concepts. For Anthony, an unexpected outcome of the paper was the achievement of an increased awareness of the need to consider the social and public implications of his work.

> The way journalists looked at the paper completely changed around what's really interesting, it's not something that I expected … we looked at temperature, we looked at pollution, we looked at all sorts of things but journalists they specifically focused on the pollution part … So that certainly becomes suddenly interesting to the general public … I didn't think that would be the main story … it was a eureka moment for me because when I do science I don't really think a lot about the other side … I do science because I'm curious … so that's something I learnt … it's amazing, it's something I probably have to keep thinking about when I do research, why do I do this? … What sort of impact does it have in society, or what makes them curious about what we do? (Anthony, scientist)

In the translation operated by the press, Anthony realises that certain aspects remained obscure and stayed in the dark while others were overemphasised to capture public interest. This process of conversion contained a simplification that displaced other critical facets that Anthony considers as important as those that became highlighted. This understanding leads him to a self-reflection on the wider purpose of his work that will have to take into consideration its public relevance. However Anthony's account also demonstrates how humbleness can be read as a lack of responsibility in doing research, resulting in a science that does not necessarily concern itself with meeting current needs, therefore an unimportant and irresponsible science. In this sense, as Haraway shows, epistemic modesty is not

always as innocent as it may seem, because it can be a way to disguise positionality and situatedness in favour of scientific objectivity (1997). Modesty is then a form of self-invisibility that allows 'European, masculine' scientific facts to be established as legitimate truth (1997:23). Anthony has not seemingly considered his position as a scientist or the purpose of his work until this particular incident leads him to confront its public relevance. He then feels obliged to interrogate for the first time his drive to 'do science', thus to cautiously illuminate his own invisible situatedness.

Another example of simplification occurring in the field is the distinction between good and bad microbes, often used by scientists as well as the media, a distinction Julia admits to use regularly despite 'knowing that it's completely wrong' thus constituting for her 'a necessary evil' (Julia, scientist). Julia has experienced what she considers incorrect priorities in terms of engaging publics with 'eye catching' topics, while 'research that I'm very proud of that's taken years to execute and write up and publish ... just wouldn't be interesting to the general public' (Julia, scientist). The process of disseminating only certain research is associated with a risk of hype between 'a real opportunity to engage the public with microbiology more broadly cause microbiomes sort of capture that interest' (Daniel, policy expert) and at the same time being cautious with the expectations publics may have for a science that may not actually be ready to be simplified. This risk is also identified in the 'Unlocking the microbiome' report analysed in the previous chapter, that states the benefits of public engagement to achieve a broader endorsement of microbiome initiatives, while calling for clarity and realistic expectations in order to control the hype (Microbiology Society, 2017).

The problem of overpromising recommendations in the public understanding of science[22] however does not intimidate policy experts like Lisa who believes that even complex science should be clarified. For her, the issue of simplification should not lead to a retreat or a lack of engagement, but instead to the establishment of a stronger and ongoing public conversation on the nuanced and iterative nature of

[22] With 'public understanding of science', the field of science and technology studies generally implies '*studies* of attempts to apply scientific knowledge or methods to problems in the public sphere' with particular interest on public attitude to scientific expertise (Sismondo, 2004:175).

science and the rejection of certainties proposed by the media, thus making visible science's inability to always provide clear cut answers. Lisa's arguments resonates with the problematic 'dominant model' of public understanding of science, identified in science and technology studies, where complex science is seen as in need for mediators whose role is to simplify what is considered legitimate knowledge for public use (Sismondo, 2004). This understanding is considered questionable because it decontextualises scientific knowledge, presenting it as matter of fact and therefore discouraging a reflexive interrogation of its assumptions.

Figure 18: A chest full of soil test kits at a public event

In the attempt to overcome what he perceives as the field's lack of appeal, Kevin offers his own dissemination strategy, mainly to do with an empathic approach. This is because he associates feeling to the appreciation of science and therefore what matters is how people 'think and feel' (Kevin, policy expert). Kevin believes that because of a negative public perception of scientists, it is more important to engage people rather than overwhelm them with facts. In this way Kevin locates himself within a position that does not necessarily value expertise but rather empathic understanding of people's interests. His response to the current dismissal of expertise, where the authority of science is increasingly discredited and distrusted in the public sphere, is one of leaving the details aside.

> Someone goes away say feeling good about soil science, that's far more important than going away knowing something about soil science because if they feel good about it they are much more likely to participate or engage

> with it in the future ... getting into granular detail you're just going to turn people off. (Kevin, policy expert)

Kevin believes in capturing the public attention with a 'wow fact' or a 'sale line' that act as impact statements focused on numbers and entertainment, such as how a 'teaspoon full of soil contains more living things than there are humans beings on the planet' (Kevin, policy expert). While Kevin shows an annoyance for expertise itself and sees 'granular' details as oddly negative, he focuses on the need for passion, claiming that change can only come with knowledge and responsibility for individuals to 'care about their soil' (Kevin, policy expert). In this sense, he highlights the importance of knowing (but not based on expertise): 'if you don't know that soil is precious, not a renewable resource, then we just carry on the way we are' (Kevin, policy expert). Kevin is not keen on the delivery of detailed expertise at public engagement events because he considers the public still too distant from soil. He sees soil as a 'hard sell' that lacks attractiveness and therefore does not capture public attention or lead people to empathise, thus underlining the importance of visibility, aesthetics and entertainment for the public to care. The only public 'attraction' soil has on offer is an earthworm.

> It's a hard sell soil, we haven't got a panda, we haven't got a dolphin, we haven't got anything anthropogenic like that that people can relate to, we've got an earthworm ... I'm not an expert on soil and that's part of my skillset is to not be an expert in something, that is not really care about things too much ... I need to be empathetic to people so I need to be able to kind of say 'ok I understand you don't really like science, I understand you don't care about soil' and for a scientist, a research scientist to say 'I don't care about my life's work' is understandably very difficult [laugh]. (Kevin, policy expert)

Kevin finds scientists' sensitivities around their work amusing and he sees his lack of scientific expertise on the topic as a strength in that he is not offended when people do not engage and he can therefore empathise with them. So while he would like people to engage with soil, he also empathises with those who 'don't care', showing the importance he places on empathy to attract people to the subject. There is therefore a tension between what Kevin considers important in terms of social

change affecting the soil and how he believes this can be achieved, through empathy rather than the acquisition of expert knowledge. A stress on empathy is also present in cooperative teacher Matt, who believes in 'building empathy with species' and using anthropomorphism for the same purpose, as a means to an end towards changing harmful soil practices.

> [Anthropomorphism] is a really useful way of getting people to empathise, if they can see something as being part of a good story. ... You want people to empathise with soil life so that they don't behave detrimentally. (Matt, horticulture teacher)

In an exploration of ways to establish a missing connection between people and soil, soil scientist Eric Brevik, et al. asks 'how do we get the general public to care about soil?' (2018:899). One of the scientists I interviewed, Joseph, poses the related but rhetorical question 'how does it relate to me?' (Joseph, scientist), for a moment identifying himself with the public. In empathising with people who may not be interested in the subject, he relies on an anthropocentric view oriented to the future that means the public will only be interested when directly affected by the use of microbial communities in agriculture. Joseph also believes there is a need for more science communication that is easily accessible to the public so that it can achieve a larger audience beyond 'some paper published in a journal that only us effectively are reading, the scientists' (Joseph, scientist).

> It may not be interesting and I understand why, because for now we don't know how can we tap into that, how can we use them. ... The public when they ask a simple question 'how does it relate to me?' I mean 'how does it change my life on a daily basis?' It doesn't, for now it does not. Hopefully in the future it will. (Joseph, scientist)

When considering public engagement, the invisibility of microbes emerges as particularly critical in capturing interest and attention. Microbes 'are in the soil but we don't see them, they don't interact with us much' (Joseph, scientist); they lack attractiveness and appeal: 'when you look at them down a microscope, they are not particularly pretty, they are not particularly exciting' (Karen, scientist). The invisibility

of soil and microbes as well as the aesthetics that do not capture the imagination are for Chris the factors leading to this field being widely neglected and not understood, thus it is fundamental that scientists strive to reach people.

> With soil, people just don't really think about it ... it doesn't get the public attention, it's not pretty flowers ... it's a hidden diversity so you don't get the aesthetic, the appeal. ... people aren't used to seeing and don't value worms ... and then when you're down to microbes it's an even harder sell ... we are constantly trying to get our message out to the public but it can be a hard sell. (Chris, scientist)

Figure 19: Open farm day: display of soil bacteria

Chris considers the nature of microbial life a 'harder sell' than worms because of its invisibility and he believes the public is not necessarily interested in what it cannot see or value for its beauty. In this sense, he hints at incorrect priorities where visible issues receive more attention than invisible ones even when these may have stronger implications: 'things that we can see and things that we can count ... we probably know a lot more about them' (Chris, scientist). In stressing the significance and neglect of soil degradation in arable fields and the loss of soil that 'ends up in the rivers, going out to sea', Chris proposes a parallel with plastic pollution, an issue that has recently become important in the public eye, while the potential harm and destruction agriculture poses to all soil life does not receive equal attention.

> Where you see lovely animals being harmed by our activities it has a lot of greater weight but actually … we are massively damaging soil biodiversity by

> cropping potentially … when you plough a field you lose the worm. (Chris, scientist)

The underestimation of practices that are damaging to soil and microbes underlined by scientists like Chris can be understood in line with what Rob Nixon has characterised as a slow violence that obscures environmental devastations from being seriously considered, 'a violence that occurs gradually and out of sight, a violence of delayed destruction that is dispersed across time and space' (2011:2). Because the temporal development of certain environmental events are not eye-catching, slow violence becomes invisible and 'spectacle deficient' (2011:47), a circumstance that can be seen at play in the neglect of soil mistreatments especially considering the invisible nature of soil and its inhabitants including worms and microbes.

Chris's frustration and willingness to 'get the message out' may also be related to his strong sense of identity as 'a microbiologist at heart but I work on soil' that makes him convinced that 'you can get across the soil messages quite easily' but the 'microbial messages' are 'more challenging' (Chris, scientist). While the public attention is captured by the 'flashing lights' of technology and in particular by a new 'tiny sequencer' (Chris, scientist) that Chris shows me in his lab, the general public may not be able to appreciate the effort behind the development of these new devices. The small sequencer raised interest at public events, but among young people there was no particular enthusiasm as the fast pace of technological innovation produces increasingly high expectations while normalising current achievements.

Chris underlines the importance of public trust and he believes in spreading the microbial message 'across the public about why public money is been spent on certain research', but he does 'sometimes wonder if they really care ... who is the public?' (Chris, scientist). Interrogating how to define the public, Chris implicitly questions the discourse around public engagement that for him seems to homogenise the multiplicity of people and publics. In a project that engages publics and their microbiome, social scientist Timothy Hodgetts, et al. argues that publics are not uniform but a heterogeneous multitude of people 'with different experiences,

knowledge, values and habits' (2018:2). However, within the narrative around the need for soil microbiology to perform public engagement, publics often emerge as reduced to a static and unchanging entity.

Together with its invisibility, some of the interviewees identify soil's long term association with dirt as one of the aspects contributing to its neglect and rejection in the public eye. For molecular microbial ecologist Karen soil 'it's dirt to most people' therefore it is not 'seen as the huge resource that actually is' (Karen, scientist), while Matt sees the dirt connotation as responsible for a prejudice and an 'indictment of soil' (Matt, horticulture teacher). The Cambridge Dictionary's definition of 'dirt' as 'dust, soil, or any substance that makes a surface not clean' (2020), is indicative of how deep the association between soil and dirt is in public imaginaries. This contributes to making soil a widely neglected issue in environmental and public debates.

A further element that diminishes the significance of soil is mentioned by microbiologists who often encounter surprise when explaining their research to members of the public who are unaware of this field of study and do not consider it worthwhile. Ben confronts the general perception of science as always being behind, thus pointing to a temporal delay in the progress of science, with people asking 'are you still working on that?' or 'have you not sorted that out yet? [laugh]' (Ben, scientist). This emphasises a denial of scientific expertise that affects these scientists in a shared experience of devaluation where their efforts are not appreciated and their field is dismissed: 'you should have it done yesterday, that's the public perception' (Ben, scientist). Despite believing that the general public is not particularly interested in soil microbial research, as a publicly funded researcher Ben acknowledges that 'as a public sector institute our duty is to make our research findings available to the public' (Ben, scientist). Thus, the invisible nature of microbes and soil, the lack of appealing aesthetics, the complexity of this novel field, the association of soil with dirt and the underlining idea that this area of study may not be worth pursuing are all considered by soil microbiologists as well as to an extent by policy experts as contributing factors to the lack of public engagement with this field. They also constitute this area of study as underappreciated and neglected in

the moment it attempts to exit the laboratory and traverse the policy and public domains.

Conclusion

In this chapter I have considered how the knowledge around the microbial communities living in soil circulates across domains of expertise and the transformation that this translation involves. I have looked in particular at a number of food growing projects that propose ways of knowing the soil and its life related to the practice of observation and learning from nature. Their experiential mode entails a form of knowledge-making that uses the senses to decipher the message coming from soil and plants. This embodied modality acknowledges and appropriates the presence of microbial communities in soil and it relates to the invisible through sensorial understandings of the world that are considered more authentic than lab-based practices. Growers relate to their agricultural fields through listening, seeing, touching and breathing, thus showing that soil and the invisible life within can still be 'seen', despite their apparent invisibility. They are convinced that this direct, sensorial way of knowing and relating locate them in closer proximity to the soil. In this context, proximity becomes a metaphor for an authentic relation and understanding of soil ecosystems.

This dynamic does not necessarily entail a dismissal of more authoritative forms of knowledge, but rather an ambivalent relationship with science characterised by scepticism and utilitarian use of expert evidence. While not relying on theoretical understandings of the soil microbiome, the food growing projects explored in my research translate scientific evidence they consider useful into growing practices. Growing with microbes entails a continuous negotiation of the relationship with the scientific domain that can validate the ethical principles growers argue for, but it does not determine a submissiveness to science's formal pathways of learning. Soil microbiome knowledge becomes instead appropriated as part of a project that poses itself as an example of an alternative system to large scale agriculture. Producing food then becomes a meaningful act of growing ethically and sharing knowledge with other farmers and the wider community. The politics of growing food in ways that

take care of soils, microbes and the environment emerge therefore in conjunction with a specific mode of knowing microbial life, allowing growers to affirm new modalities of relating with the land and with other lives.

As for the policy and public realms, the process of knowledge translation presents more attrition. The soil microbiome field emerges with an orientation towards protecting soils and therefore it involves the need for translation into policy and broader public awareness, but the discussions considered in this chapter demonstrate that this is not a straightforward endeavour. The attempts to translate the knowledge of soil microbial communities are characterised by a tension where this field of study is reduced and 'forced' into trivial oversimplification. This form of transformation is sceptically received by soil microbiologists who are keen on conveying the importance of soil microbial communities but are not willing to diminish the science to the point of rendering it meaningless. Soil microbiologists recognise policy requirements for clear indicators that do not allow for the granular specificity of their field to emerge. They understand the need to simplify their knowledge for publics to engage and care. Their reluctance derives from the difficulty to communicate the value of soil microbes, together with an untenable pressure they sense to sell their work in ways that entail the loss of important details and complexities. This results in a process of displacement of concepts and context where the value of microbes becomes lost.

Policy demands to translate and the obligation to engage with publics are therefore associated with a debate around the intrinsic versus instrumental value of knowledge (and of the soil microbiome). The dispute around knowledge created for its own sake versus the value of its application is at the heart of this tension between soil microbiologists and policy makers in a relationship that is clearly far from harmonious. This distinction plays a role in the process of knowledge translation because it sets certain priorities around what constitutes worthy knowledge, a knowledge that becomes policy. Unlike pandas, dolphins or flowers, soil microbial communities are invisible to most people and because of their lack of appeal, together with the novelty and complexity of the field, they face underappreciation from funders and publics. These dynamics make the translation of soil microbiome

knowledge into policy and public domains convoluted and problematic, contributing to a construction of the microbial object as neglected and underappreciated.

Chapter 6. Becoming with microbes

Introduction

After having explored different versions of the future interwoven in the constitution of the soil microbiome and the ways in which this knowledge circulates and is transformed by the spaces it enters, in this chapter I return to the microbial as a primarily scientific entity. I delve more closely into soil microbiologists' relationship with the microbes they study, how they deal with and talk about microorganisms and what it means for them to relate to this invisible entity and to 'feel' microbes. Unpacking some of the elements explored in the previous chapter, I consider how the invisibility of microbes not only affects the neglected nature of the research field, but also shapes the relationship between soil microbiologists and their object of study.

In exploring scientist/microbe relationships, I am looking for the possibility that scientists may embrace a more horizontal understanding of microbial life, beyond an exploitative narrative around agricultural technofixes. I examine whether soil microbiologists are interested and willing to engage with microbes in transformative ways. In order to consider these possibilities, I prompt soil microbiologists to think through concepts such as behaviour and self-awareness that are located beyond their training and practice. I invite them into the exploration of forms of relating that can allow for the recognition of microbes as lives intrinsically worthy and valuable. Rather than expecting a particular reality to be revealed, I am aware that by asking microbiologists to think beyond their epistemological framework, I am inviting them to create and explore novel sensitivities, modes of relating and possibilities of becoming. These kinds of questions are inspired in particular by the work of Donna Haraway (2008, 2016) and Lynn Margulis (Margulis and Sagan, 2002) on the interconnected nature of life and on symbiotic relationships, to which I return later in the chapter.

In my interviews with scientists, while touching on the thorny realm of relating to microbial life proved to be a delicate endeavour that often required lengthy explanations on my part, I persisted nonetheless. This imposed reflexivity elicited

surprise, laughter, unease and more serious reflections among microbiologists, prompting the discussion I undertake in this chapter. In exploring these dynamics, I propose two related arguments. The first is that through definitions, conceptualisations and particular approaches to microbial life, soil microbiologists shape and reinforce not only a particular characterisation of the microbial but also the very definition of the human, framed through an anthropocentric separation from microscopic life forms, thus re-establishing and reconfiguring the division between human and microbe. My second related argument proposes that, alongside this separation and once again confirming the non-linearity of the field, soil microbiologists are also able to overcome rigid boundaries, showing that human actors differ in their politics around microbial life. When they allow themselves to become personal with microbes, soil microbiologists displace a hierarchical attitude and embrace a more horizontal approach to microbial life. In this process, they can 'feel' microbes and become transformed as a result because they allow themselves as human investigators to be influenced by microbes, rather than being the only actors able to affect and influence. As I will show, becoming with microbes in this particular context emerges as an entanglement that is both conceptual and embodied.

We don't really see them

The scale of microbes, laboratory routine and the specific focus of her work are the elements that lead early career researcher Rachel to a disconnection from her object of study as living and to 'forgetting' that microbes are alive.

> It's really hard to actually imagine them in real life because they are so small; I'll get a flask of my culture and I know that it's full of lots of cells but I don't really think of it as living or anything even if obviously it is. (Rachel, scientist)

Not seeing microbes for Rachel almost translates into them not actually being there, thus showing that the invisibility of microbes has an impact on the very definition of living, where life is what is there and can be seen. In this sense, 'knowing' that microbes are alive is quite different from remembering and 'feeling' that they are.

The relevance of scale in the relationship with living forms is confirmed by early career researcher Deborah who has a number of 'favourite soil animals' (Deborah, scientist) of whom she talks fondly. These are not microbes but insects like springtails, 'one of my favourites', and pseudoscorpions who are 'really fun' (Deborah, scientist). Because she is quite familiar with these animals she has a particular attachment more to do with 'knowing' than 'feeling': 'I'm constantly aware that they are there ... but it's not like I attach to them like I would attach to a dog'. Thus Deborah shows how scale and invisibility have implications for a distance that can determine the level of possible attachment, where microbes on the other hand 'are quite conceptual' (Deborah, scientist).

Alongside scale and invisibility, the routine nature of work emerges as an important element that seems to prevent some of these scientists from engaging with microbes as living beings. Deborah's description of sometimes boring tasks reminds me also of how science is made of manual tasks like sowing and weighing.

> I had these mash bags, I filled them up with straw and then I pat them in the sowing machine to close them up and then I buried lots of litter bags in the soil and every month I went back to dig up a few so I could see how the different litter types in the different soils, how fast they decomposed. (Deborah, scientist)

The way the decomposition of litter is assessed appears as strikingly simple, at least at first: 'just weighing the litter ... which was actually really hard cause the scale has been really annoying' (Deborah, scientist). She then describes a typical day: 'when I do fieldwork, I have to make sure that all the equipment is there … I don't have a license so I cycle to the farm ... I arrive there, I do my stuff in the field, I get really hungry for lunch, come back really tired' (Deborah, scientist). Similarly, while Rachel says that her work 'varies' and the description of her daily activities includes tasks carried out between the lab, the greenhouse and the office such as 'preparing the samples', 'sending them off to get the DNA sequence', 'growing some plants' and 'little tasks like that', this variety does not seem to distract her from the perceived routine of her 'protocol' (Rachel, scientist). A public agricultural event her university

was involved in helped Rachel to remember the excitement of dealing with microbes, an enthusiasm that the routine of work has contributed to obfuscate.

> It's become so routine to me that I don't really stop to think 'Oh, they're actually alive' I don't know it's just, I kind of just forget a bit sometimes. It's very easy to forget the bigger picture when you're doing anything specific like this. ... It's really nice doing outreach things like that because it reminds me of what the bigger picture is ... it was really weird seeing people so surprised to be looking at microbes through the microscope when it's become so routine to me. I'm just like 'Oh yeah, they're just there' ... I don't get that very often cause it's just routine to me. (Rachel, scientist)

Thus the purpose, routine and specificity of her work contribute to the act of 'forgetting' and to not questioning what living means. For Rachel, daily routine makes it harder for the wonder and the awareness of the living microbes to emerge. Given that both Rachel and Deborah are early career researchers, their sense of routine may be linked to possibly repetitive and monotonous tasks undertaken because of their junior position. I was further reminded of the routine nature of the practice of science when I encountered the presence of typically domestic appliances such as the washing machine pictured below in a state-of-the-art facility for plant and microbial research (Figure 20); or when listening to molecular soil ecologist Isabel as she describes samples delivered using everyday items that are not immediately associated with the practice of science such as 'cool packs like in a picnic box' (Isabel, scientist). These serve as an indication that scientific laboratories are spaces where routine, repetitive and often unsuccessful operations are carried out. Accounts of the mundane practices of the scientific laboratory have been well documented in science and technology studies (Knorr Cetina, 1981; Latour and Woolgar, 1986). These have allowed the ordinary routine of science to emerge and displace a focus on invention and discovery.[23] In particular, sociologist Lisa Garforth discusses the uncomfortable self-awareness of scientists when faced with the boring

[23] If this mundanity was brought more strongly to the public attention, I argue that it could contribute to normalise the daily practice of science and dispel a perception of the scientific endeavour as a creative and always successful process.

nature of their daily tasks (2012), activities such as the ones reported by my participants. The routine duties involved in the daily practice of these soil microbiologists are significant in that they contribute to their 'unawareness' about microbial life, in an act of 'forgetting'.

Figure 20: Lab room with washing machine, showing the mundanity of science

But it is also microbes' very short life that justifies scientists in their detached attitude, with molecular microbial ecologist Karen pointing to the relevance of the microbial community rather than 'an individual bacteria' that can have 'a half-life of five hours' (Karen, scientist). Unlike the kind of temporality oriented towards the future explored in chapter four, Karen refers to the impermanence of microbial life as a way to justify her distant relationship with microbes. She implies that because of their short lives, microbes cannot be considered as individuals. This underlines how microbial life is understood not only through spatial but also temporal conceptualisations.

> My own personal way of looking at them is I treat them more as a community ... that's where they are holding a specific role of function so I tend to think more as a bacterial or microbial community and what that's doing and of course, you know they do have a very quick turnover, they have a very quick life cycle. (Karen, scientist)

Soil microbiologists often refer to what microbes do as a function. Karen's reference to microbial function implies an anthropocentric view that considers microbes only valuable for what they can do for humans. Microbiologists want to know 'who is

there and ... what they're doing' and 'understand diversity and function of microbes' (Nicholas, scientist). Among the functions soil microbes 'perform' is nitrogen fixation, iron conversion, growth promotion and disease suppression, thus what they do is considered relevant because it can be exploited and harnessed in agriculture for its potential to protect crops and provide them with nutrients. By reducing microbial action to a function, these scientists do not seem to consider that any living organism could be categorised for the functions they perform. Humans could then be classified for converting oxygen into carbon dioxide.

Ben, a plant and soil microbiologist, also resorts to the function of the billions of colonies he studies rather than the individual microbe, thus implying the difficulty of connecting with life forms when they are in unimaginable numbers and reinforcing the insignificance of microbial individuality. By defining them as a cohort, Ben aligns their role and importance with scientific purposes and implies the irrelevance of thinking about them in any other way. Seeing them as a colony as opposed to individuals, while valuable in understanding the integrity of the community, accentuates microbes' dissimilarity from humans, thus lack of individuality creates a distance between humans and microbes. Ben's hesitation in this quote indicates a slight discomfort with the subject.

> When you're doing DNA extractions or other molecular biology techniques you have to have faith that you're dealing with things, ... there has to be a bit of faith actually when you're doing that ... I don't spend a huge amount of time thinking about [laugh] the size of microbes really, I mean, it's really, it's almost like a cohort, isn't it, you think about the function of the microbial community ... we're looking at microbial colonies which contains billions of microbes. (Ben, scientist)

When I ask Ben how he conceptualises microbes given their invisibility, he seems to sense the epistemological jump implied in my question and initially protects himself by denying their invisibility: 'they're not invisible anyway, you can see them under a microscope [laugh]' (Ben, scientist). In emphasising their visibility, I have the impression that Ben is attempting to normalise microbes so that he can avoid discussing the problem of relating to them. He then acknowledges the difficulty of

not seeing them that requires some faith in the analysis process. In this sense, despite underlying their visibility, Ben still finds it difficult to 'see' them.

Owen, who is a scientist with interdisciplinary expertise ranging across soil chemistry and biology, also objects to the invisibility of microbes but once again this does not facilitate him in relating to them: 'if you have a cow you know where is the cow. ... if you want to track a bacteria probably is [laugh] is more complicated' (Owen, scientist). Considering the straightforward way to relate to other animals where 'you only need your eyes', or to 'plants that you can see', Owen contrasts the 'abstraction' required to 'imagine in my mind' soil microorganisms (Owen, scientist). This underlines the problem of individuation as an important aspect of conceptualising life forms, where the mediation of technological tools to identify invisible life forms poses a problem in the way he can relate to them. Thus for Owen the technical ability to see microbes does not translate in the possibility to establish an embodied rather than abstract relation with them. Also pointing out the difficulty to 'see' microbes, agricultural microbiologist Margaret acknowledges the importance of remembering that microbes are alive in a way that suggests a sense of duty rather than an intentional drive: 'I always have to keep that in mind, yeah but we don't really see them ... but we have to think of them as alive things' (Margaret, scientist). Thus, the inability to 'see' and relate to microbes as individuated and significant living beings, makes it necessary for microbiologists to remind themselves that microbes are alive.

Aside from invisibility, scale, routine, short life cycles and lack of individuality, a fundamental reason that underlines a detached relationship with microbes as living entities is the constitution of science as objective and strictly removed from emotion. The objectivity element of the scientific project does not necessarily allow for an awareness of microbial life in the sense interrogated in this study, as valuable in and for itself. Soil microbiologists' attitude to the microbes they study takes ambivalent forms located between the inability to 'see' them and a perceived need for a detached position. As explored in the previous chapters, this element is also evident through the lab's compost mixing machinery and clean sowing pots, which demonstrate a microbiopolitical attitude of control towards microbial life. This

approach draws on an ideal of objective science that does not allow for a connection with microbes as living beings.

Following Astrid Schrader in her discussion about how to care and for whom (2015) can assist in understanding the difficulty soil microbiologists encounter in relating to microbes. When Schrader presents her classroom with an article about paintings of leaf bugs deformed by radiation found in the aftermath of the Chernobyl nuclear accident, her students struggle to care for what they see as insignificant insects compared to the destruction of human life that followed the disaster. Their reaction leads her to reflect on the questions of 'who deserves our care and protection?' and 'how do we begin to care?' (2015:3). A possible way to become affected for her requires the displacement of the implication that engaging with leaf bugs, or in the object of this thesis, with soil microbes, means disregarding the human. Thus, caring for one does not imply inattention to the other. It is therefore possible that the soil microbiologists interviewed also do not know how to care or what care would look like in a microbial context because to become involved would be to prioritise the microbe over other actors involved in the soil field such as growers. Furthermore, there is a sense that microbes are required to be constructed as objects of enquiry rather than living beings so to secure the perpetuation of the separation between human investigators and microbial entities. While none of the scientists declare straightforwardly their concern that this dualism may be overcome once their relationship with microbes is allowed to become deeper, this dynamic emerges from the descriptions of their detachment from microbes. In this sense, microbiologists' engagement with microbes is structured, limited and policed by their practice.

This distant position is reflected for instance in bioinformatician Joseph's attitude to what he considers an 'esoteric' topic, namely remembering that microbes are alive, something he finds uncomfortable: 'I would need to have this question before to really get it down through me, to filter through my head' (Joseph, scientist). My request to reflect on microbial 'aliveness' pushes Joseph's thinking framework towards unexplored areas that are not embedded in his scientific practice or training. Joseph emphasises a contrast he perceives between a neutral scientific method and emotional and philosophical expression that in this context he sees as inappropriate

and damaging to the pursuit of science. Because for Joseph this is a job, there is a need for objective detachment where remembering that microbes are alive is considered detrimental as well as irrelevant.

> It's quite an abstract way to think that the bacteria I sequence they are alive. I mean I know they are alive but I don't think what they've been thinking, what they've been eating on a daily basis, if they were happy or not. Maybe it's just me I'm not the most, let's say esoteric I think that's the word, I feel it's a bit like a job ... emotionally I'm not much connected with these bacteria, even though I like some species and I don't like some others ... for me these are mostly numbers, I like when the numbers make sense, when they represent something ... but I don't have much emotional connection with them ... I'm trying to be objective, not to favour any bacteria. (Joseph, scientist)

In listing human activities and states of mind such as thinking, eating or being happy, Joseph implies that these elements are irrelevant in the microbial realm. He criticises those who 'have very emotional approach to their work' because 'on the verge of being skewed towards something' (Joseph, scientist). Developing an emotional connection with microbes would mean to introduce elements of bias and distortion and ultimately to skew the science by favouring certain bacteria over others. For Joseph, this could lead to seeing microbes even where they are not there because they 'want them to be there' due to this 'emotional bond' (Joseph, scientist). Joseph has his bacterial preferences but he is keen not to favour any species over others. Because he considers an attachment to them as potentially detrimental to the practice of science, he is reluctant to allow himself to 'feel'.

In his attempt to accentuate the separation between humans and microbes, Joseph also emphasises the importance of the symbiosis between plants and microbes while downplaying the relevance of the interaction between microbes and humans. He also prefers to think that humans have much higher standards than flies when choosing a mate and this points to his perceived threat to the broader hierarchical separation between human and nonhuman posed by comparing the members of these different realms: 'I'm aware of some studies on fruit flies that they choose their mates based

on the gut microbiome structure, which may be true that we do the same, I would like to think not' (Joseph, scientist). In this sense, human exceptionalism emerges in the contrast between a supposed superior human standard and a lower insect realm driven by physiological determinism.

At this point of the discussion, Joseph returns to his main expertise, the field of bioinformatics he considers 'science in pure form' where he can answer based 'on data' (Joseph, scientist). For Joseph computing is 'intuitive, very logical' in that there are no 'faults' (Joseph, scientist), thus his expertise in informatics is key to understanding his 'science' position. Joseph also proposes the extreme parallel between scientists and robots that 'minimise [their] personal opinions about data' because data 'doesn't change, the way you look at it doesn't change the number, doesn't change the sequencing' (Joseph, scientist), thus objectivity for him is crucial to the production of reliable results. Likewise, Isabel, a molecular soil ecologist, shows a clearly detached relationship with the microbial communities she studies, employing a somehow cynical description of what she does. Isabel conceptualises microbial life within a utilitarian approach that does not allow her to engage in a relationship with microbes.

> As a molecular biologist I see them as DNA ... I don't look at them in a microscope and I don't grow them in plates, I don't do that, I just, I kill them all, remove their DNA and just use their DNA … they are like ID card, I just steal their ID card and look at that. (Isabel, scientist)

The reference to 'killing' contrasts in part with the desired outcome Isabel is pursuing of erasing the living relevance of microbes, but it does retain the effect of conveying her neutral detachment and purely utilitarian attitude. Among soil microbiologists, the disposal of microbes, or as cooperative teacher Matt reflectively considers 'killing the thing you're studying' (Matt, horticulture teacher), is the necessary end process of the management of microscopic life. This administration and policing of life - and death - resonates with the Foucauldian concept of biopolitics as the 'subjugation of bodies and the control of populations' put into practice through the regulation and supervision of all aspects of human life (1978:140). Within the discussion on the policing of microbial life in a biopolitical sense, the administration of microbial

populations needs to be carefully in place throughout all processes of life. As discussed in chapter four, the microbiopolitical constitution of the microbial entails manipulation and management, but these interventions also involve death. Rather than constituting the final scope of this government of life however, death is rather one of its inevitable aspects. I was further reminded of the intrinsic link between the management and employment of microbial life and the control of its death at Isabel's laboratory, where I was shown what is known as an autoclave (Figures 21 and 22). The autoclave is a piece of machinery that disposes of microbes, nothing less than a chamber employed to ensure the end of microbes. When they have served their purpose and are no longer needed, microbes are safely sacrificed.

This killing however is not murder because only 'man' can be murdered, while animals are sacrificed (Haraway, 2008). The question of killing for Haraway is not about extending a moral ban to kill to new 'others', but about 'facing killing' with responsibility and questioning killability altogether (2008:81). It is about making the practice of microbial killing open. The issue therefore is not necessarily killing itself, but 'making beings killable' while others are constituted as not killable (2008:80). A focus on the 'command "Thou shalt not kill"' paradoxically continues to allow the killing of some creatures rather than others (2008:80). In this sense, Haraway questions the ethics of rendering one species killable as opposed to others who are defended on often merely anthropomorphic grounds. If the killing of a particular species is opposed, such as the panda and dolphin mentioned by communication officer Kevin in the previous chapter, then other species or even entire taxonomic domains are made killable. What is needed therefore is not merely problematising the killing of some species, but questioning the process of legitimisation that makes a particular species or group killable altogether. This requires bringing to the open the process of making someone killable by diminishing, devaluating and depersonalising its capacities. This distinction becomes relevant when applied to the microbes facing death in the lab. The legitimation to kill soil microbes manifests in the process of denying their relevance, agency and intention while unquestionably rejecting their sentience, self-awareness, free-will and consciousness, all elements I explore in the following section. In order to question the making of microbes killable

in scientific research, it would be necessary to counter these processes of denigration at play in the scientific and social constitution of microbial life and all life forms, so that no species or domain of life is regarded as appropriate to kill.

Figure 21: Autoclave at Isabel's lab

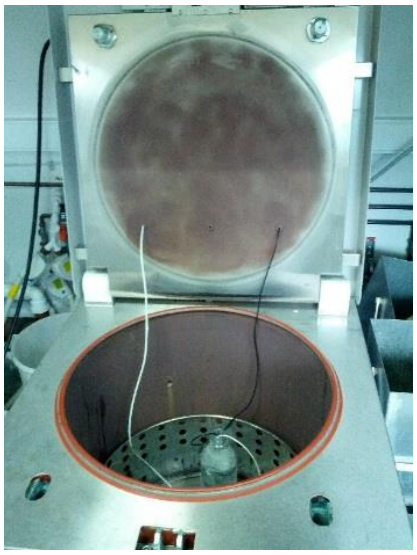

Figure 22: Close-up of autoclave

With soil microbes however, death in the autoclave becomes sterilised disposal. Autoclaving does not face the act of killing and it does not think with killing. Instead, killing is an unreflexive routine practice carried out with nonchalance and no great ethical consideration because, as I discuss in the following section, microbes are not truly considered living beings but rather 'entities' or 'units'.

Do microbes behave?

Microbiologists justify their abstract relationship with the microbes they study by resorting to their scale and invisibility, the routine and specific nature of work, the shortness of microbial lives and their lack of individuality. This detachment from microbes emerges in the context of a particular life form that is seen as distant, a specific kind of nonhuman that is too dissimilar to relate to. Having considered the difficulties soil microbiologists encounter when faced with their own relationship with an invisible object of study, I now address how definitions of humans and microbes shape and construct each other through strategies and exclusionary language practices aimed at denying agency within the microbial realm. How do

these definitions re-establish the anthropocentric separation between human and microbe?

I take the word 'behaviour' as a signifier that comes to epitomise the way these definitions are established in the field. This term carries a number of meanings and concepts that soil microbiologists have reasons to avoid when referring to their ineffable entities of enquiry. The act of behaving is seen in this context as suited to describe human actions only and is able to spark reactions of unease when referred to microbes. When discussing with soil microbiologists their attitudes and relationship with microbes, it was not until the interview with bioinformatician Anthony, the eighth scientist I talked to, that the concept of behaviour surfaced as significant, in that it seemed to pose some problems in Anthony's own narrative. After that conversation I began to discuss the word behaviour and its cautious use in the microbial domain with soil microbiologists. Bringing the word behaviour to microbiologists' terrain was valuable in inviting them to the boundaries of their own practice and language, thus providing insights on how microbes are currently conceived in soil microbiology. Rather than highlighting scientists' lack of reflexivity or taking the stance that microbes do indeed behave, the purpose of this discussion is to engage with the uneasiness that microbiologists display around the word as a way to present a problem, reflect on its ramifications and consider its relevance.

I found in particular Anthony's discomfort around microbial behaviour significant because it is anchored to the perception of an element of agency that he is not certain he is willing to accord to microbes. At the same time he is confronted with the fact that by 'doing', microbes inevitably end up 'behaving'. Anthony first refers to microbes as simple 'little units' thus minimising and diminishing their agency, capacities and life strategies.

> As much as I'd like to think they are complex they are actually quite simple, that's how I see it, they are very simple, they have certain rules that they follow and if you can decode all these rules, I believe that we can understand them really well ... I certainly sort of see them as little units that are governed by their small rule, set of rules. (Anthony, scientist)

The ‘rules’ mentioned by Anthony imply a calculable object of study, while the word unit is a detachment strategy that provides the objective and rigorous description needed for researching the microorganisms of the soil without incurring philosophical debates on their agency. Saying that these units react is a whole different story from saying that these living beings ‘behave’. When Anthony starts to confront these sets of rules more directly however, things become rather complicated.

> Their… it’s not really behaviour, but sort of yeah, behaviour is alright I suppose yeah, how they handle situations seems to be fairly limited, but yeah, actually it might not be limited, I don’t know [laugh] actually they do, they are very complicated because they don’t always follow the rule actually you’re right, I mean sorry I’m wrong, they don’t always follow rules. ... there’s some weird things going on, there are always that mutation, evolution that makes them so tricky to study [laugh], yeah. So they’re simple but I, not quite like human, I don’t see them like human ..., I haven’t really thought about this, no [laugh]. (Anthony, scientist)

Anthony’s response seems to show that he is improvising and figuring out what he thinks, in contrast with other quotations where my respondents are clear and precise. Anthony has not spent time reflecting on the matter because this is not what he is required to do in his practice. On one hand considering their resources as limited, on the other accepting that behaviour can be used but with caution, Anthony seems uncomfortable about a possible ambivalence he has now built where microbes eventually emerge as rather complicated and highly resourceful. From simple units, microbes cease following rules and become ‘weird’ and ‘tricky’. Faced with my question around a possible analogy between microbial and human communities, prompted by the anthropomorphic way he talks about human gut communities (‘communities change, communities compete, communities die’), Anthony separates microbial responses from human behaviour by proposing that microbes lack morals. From the comparison with humans, microbes emerge inevitably defeated.

> I can't really sort of humanise microbes I think they don't quite have the same moral, values as we have [laugh], yeah, as much as I want to sort of treat them as humans I think they operate in entirely different rules. (Anthony, scientist)

Anthony is wary of being entangled in a complicated debate around the difference between humans and the 'animal world' or 'the entire animal kingdom' (Anthony, scientist). At this point he considers how chimpanzees have 'a more human element' and he mentions a recent paper showing how chimpanzees within close social groups have similar microbiome. In a possible parallel with humans, Anthony feels more comfortable talking about mammals than microbes, showing not only that similarity is significant in conceptualising and relating to different life forms, but confirming once again that microbes constitute a specific form of nonhuman because of their scale, invisibility, short life cycle and lack of individuality.

In defining microbes and discussing behaviour, as shown, Anthony resorts to a number of metaphors that portray them as simple units that follow rules. Metaphors pervade everyday thought, action and the way we perceive the world (Lakoff and Johnson, 1980). They show the concepts that constitute the architecture of our activities, a conceptual systems we may not be aware of. By paying attention to the language used, it is possible to identify the metaphors 'that structure how we perceive, how we think, and what we do' (1980:4). As noted by Evelyn Fox Keller, 'all language is performative', including scientific language, in that it frames the problems and the questions asked (1995:xi). Scientific language matters for the direction scientific research will take. It impacts the agenda, the questions asked and the types of experiments carried out. For Keller, metaphors are powerful because of their reference to conventions and resemblances and their effectiveness also relies on the influence of the experts who employ them. Scientific metaphors reflect prevailing social perceptions and therefore change accordingly.

In the context of soil microbiologists discussing microbial communities, exploring their language and metaphors can reveal insights into their conceptual system in the perception of microbes. When soil microbes are defined as units that respond, this language finds its shared resemblance with an idea of microscopic life as unintentional and lacking agency. When molecular microbial ecologist Karen

considers bacteria as 'a cell which is determined to respond to its environment and reproduce' (Karen, scientist), she relates her description to shared deterministic understandings of a cell devoid of purpose. This is how scientists' metaphors are performative in the sense that they reinforce lay perceptions, in this case denying microorganisms' intention and agency and allowing for a deterministic definition that excludes the possibility of microbial free will.

However, while hesitant in the use of the word behaviour, microbiologists are often betrayed by the very language they use to talk about microbes, for instance when describing microbial actions in ways that are inevitably associated with human behaviour. In this sense, there is an ambivalence in suggesting strong boundaries between the microbial and human worlds and the employment of humanising metaphors to describe microbial action. In exploring this, I do not hold that anthropomorphism has necessarily a negative connotation, but that there is an interesting fluctuation in those who reject a connection with microbes and who clearly demarcate the human and microbial realms through the use of depersonalising language while at the same time accentuating the similarity between microbial and human behaviour through the employment of humanising metaphors.

Despite his willingness to reinforce the divide between humans and microbes, Anthony's description of microbial communities in the human gut can be seen in parallel with human societies, illustrating how resorting to human metaphors to describe microbial life is an inescapable element of scientific description, despite the stated objection to personifying microbes. Similarly, while Joseph strives to be an objective scientist, when he discusses the changing nature of certain bacteria that turn from beneficial to harmful, he depicts them as showing 'their real face' and he talks about microbes who 'behave badly' or 'change their lifestyle' (Joseph, scientist). Joseph has been looking at the interaction between plants and bacteria and describes plant roots as 'hot spots' of food for bacteria that means 'there will be a fight, there will be a competition plus there will be interaction with the plant' (Joseph, scientist). Thus the microbes that Joseph considers 'mostly numbers' in an avoidance of emotional attachment, now become agents of bad behaviour. Likewise, Isabel gives

microbes human attributes while at the same time showing discomfort for the word behaviour because it can convey the idea of purpose.

> It sounds like they have a purpose which I don't know, they're microbes [laugh]. ... they would answer to a stress or to a way of farming but they would just try to survive so, but yeah the, I don't know if behaviour, I think it would be more like response, adaptation, behaviour sounds like there's an idea behind while they don't… (Isabel, scientist)

Isabel prefers the notion of response or answer to behaviour because better suited to deny that there may be 'an idea' behind microbial actions. Accepting microbial behaviour poses a threat to the accepted separation between human and microbes. In order to set and maintain this boundary, the word behaviour is generally replaced by more neutral and less intentional alternatives such as response, function and reaction, in an implicit practice of restricting microbial agency: humans behave; microbes respond. Microbiologists also define microbes as units or entities to reinforce this exclusionary boundary.

> That's the point of microbes, they just try to survive and they will survive, they will increase more if they are comfortable ..., but they don't try to just be nice and help the soil. (Isabel, scientist)

Isabel depicts microbes as selfish because they attempt to survive, with an assumption that the drive for survival is a particular microbial feature not extended to other life forms. Despite her intention to be detached, Isabel gives a fond description of a 'new kind of bacteria', some 'guys' identified only a few years ago that are 'our new toy' (Isabel, scientist). The way she talks about these bacteria shows that in certain circumstances Isabel is able to have a 'feeling' for microbial life. This seems to be related to the specificity of the bacteria under study that has been individuated from the rest of the community, showing once again that individuality allows for a more straightforward connection as opposed to large cohorts. She later describes the microbes inoculated into a field by personifying them almost to the point of showing sympathy for the newcomers who are 'alone'.

> When you spread them in the field they will be outcompeted because they are alone there and they will be crushed by the other microbes in the soil but if you add a soup of them maybe they will get stronger, they can stay more in the soil, ... they have to survive which is very difficult for them so I think it would be a way to help them stay longer so they can actually benefit the soil. (Isabel, scientist)

Here Isabel's concern for microbial communities is related to their connotation as the 'good' microbes that benefit the soil. In this depiction, microbes are on their own in a challenging environment and therefore in need of protection from the harshness of life but at the same time they are referred to as a 'soup', a mass that depersonalises them and focuses instead on their potential. In this sense, the concern coexists with the need for microbes to benefit the soil 'because if you add them it costs a lot of money to produce them and they just don't survive, there's no point' (Isabel, scientist). Highlighting the market driven nature of the field, entangled with a solution-based approach aimed at the development of products, the performative nature of her metaphors acquires an ambivalent shade that depicts microbes as both mere conduit to a good soil and as vulnerable lives in need of assistance. A form of sympathy is also present in Owen's reflection on the struggle of the soil microbial communities: 'it's very complicated the work for them ... they can't move, they cannot move too much' (Owen, scientist). Also inevitably personalising microbes, Jack talks about how soil bacteria form clumps 'and they don't see their neighbour and there's nothing connecting them with their neighbour' (Jack, scientist). Thus Jack uses the anthropomorphic metaphor of 'seeing' while at the same time firmly objecting to the idea of microbial agency and behaviour, in that we can only talk about behaviour 'not from their perspective, from our perspective' (Jack, scientist). In this way, Jack allows microbes to see but not behave.

> So it's a term that we probably shouldn't use because yeah, we can say that certain microbes would behave in this way but it's more, certain microbes would respond in this way, or react to this stimulus. (Jack, scientist)

For Jack, behaviour is a human interpretation and therefore it risks to 'personalise it, you give it ... what's the word… consciousness' thus 'putting our interpretations into

something else that is literally responding to stimuli.' (Jack, scientist). Jack relegates the word behaviour to a mistaken human interpretation of microbes and presents microbial response as the incontrovertible objective fact. He also implies that consciousness is a value to preserve within the human realm, thus entailing microbial predetermination. By introducing a strong normative element in the use of the word behaviour and consciousness, Jack shows a concern for the risk of eroding the separation between human and microbe and he seems to hope that through the careful selection of his words he can preserve human exceptionality. In a similar manner, Ben is keen in subtracting awareness and sentience from microbial action, even if he admits that microbes may behave but only with conditions attached (they do not know that they are behaving). He then conflates the terms function and behaviour, thus diminishing their significance as living beings in favour of their instrumental value.

> Behaviour? Yeah, I mean it's obviously a different, they 'behave' in a certain way, they're not really aware that they are behaving in a certain way but they have traits and they are able to do certain functions, so a function, is that behaviour? Probably, ... some are able to move freely, some aren't able to do that, so yeah that's a behaviour, so they do behave and some cause disease, some don't and from a human point of view, the ones that cause disease in people or on crops are behaving badly [laugh]. (Ben, scientist)

When Ben wonders if a function is a behaviour, he is looking at the key distinction between microbes as units to be studied for their potential agricultural use and microbes as agents. In other words, as long as microbes are constructed as performing functions, they can be manipulated and used without debates on their intention or purpose. Ben acknowledges that 'good' and 'bad' behaviour are human-centred definitions based on the agricultural use of microbes. His ambivalence emerges when he grants microbes the capacity to behave but then considers this behaviour as selfish in how microbes switch from assisting plants to causing them disease: 'a microbe and its behaviour, it's ultimately selfish, it's doing what it can to meet its own needs' (Ben, scientist). Through the performative nature of language, Ben allows the coexistence of these contrasting depictions of microbes as mere

predetermined units and as agents of selfish behaviour. These discussions led me to the understanding that if behaviour in microbes is accepted and extended to include concepts such as self-awareness and consciousness, both notions mentioned with disapproval by the microbiologists, then the manipulation, harnessing and disposal of these organisms for the sake of human interests may require stronger ethical and philosophical considerations.

Alongside self-awareness, another concept that encounters resistance when presented to the soil microbiologists is microbial ancestry. The exploration of this topic in my interviews was provoked by Margulis' argument that humans coevolved with microbes through a process of symbiosis that involved the acquisition of other organisms' genome and resulted in long term changes called symbiogenesis (Margulis and Sagan, 2002). This is a process where 'associations lead to partnerships that lead to symbioses that lead to new kinds of individuals' (2002:90). Microbes are therefore 'the engines of evolutionary change' (2002:87). Margulis argued that humans contain ecological communities and they should consider microbes as their ancestors. For her, the awareness that microbes influenced and directed evolution does not need to spark a human sense of shame and affront (2002). On the contrary, there is a sense of wonder in acknowledging that microbes played such a fundamental evolutionary role. Drawing on these arguments, I wanted to examine whether Margulis' ideas are accepted by soil microbiologists. Embracing microbial ancestry could entail a higher respect for them as living beings and could represent the basis for the novel and transformative relationships with the microbial that I am interested in exploring.

Perhaps unsurprisingly, in line with the ridicule that surrounds symbiotic theories, the soil microbiologists interviewed show resistance and respond with irony and jokes to the idea of microbes as human ancestors. Their reactions are significant in the refusal to see microbial role in human evolution. Ben considers microbial ancestry as a step too far: 'first life on Earth was very, very, very primitive, so I mean I suppose you could argue that everything comes from that but, you know, it's a long… [laugh]' (Ben, scientist). In the attempt to counter the idea of microbes as ancestors, Ben runs out of words as if he has not thought about this before. Jack's

irony gives me the impression that he does not consider this topic worthwhile in the same way he is not keen on discussing microbial behaviour.

> We have definitely coevolved with them but I, and, I, and well I suppose you could go to the point where every single eukaryote cell contains prokaryote cells so, you know, yes we are prokaryotes then, OK [laugh]. Just multi-cellular. (Jack, scientist)

In order to minimise the possibility of concepts of sentience and consciousness being interrogated in the microbial realm, soil microbiologists also downplay the importance of the microbial capacity to communicate. This particular ability, known as quorum sensing, surfaced in the interviews as a marginal topic but it stimulated my interest in exploring the concept further. Quorum sensing is the process bacteria use to communicate with each other through the release of chemical signal molecules (Waters and Bassler, 2005). This chemical communication allows bacteria to synchronise their activities but it is described with the assumption that humans do not do the same. Most interestingly, 'quorum sensing confuses the distinction between prokaryotes and eukaryotes because it enables bacteria to act as multicellular organisms' (2005:319), thus the communication may blur the dichotomy between eukaryotes such as humans and prokaryotes[24] with regards to the ability to communicate.

Margaret admits that microbes interact but she still does not consider behaviour as the correct word, so they can 'communicate through signalling, but I'm not sure we can say behaviour [laugh]' (Margaret, scientist). Reducing quorum sensing to a function and defining bacteria as a cell is Karen's attempt to settle things once and for all.

> I don't think they have sort of necessarily self-awareness but bacteria do respond to each other, there's things like quorum sensing which is how they are able to detect other bacteria around them so there's functions like that, I mean I don't necessarily feel bacteria as a self-aware entity in any way or form

[24] Eukaryotes are organisms whose cells contain nuclei; prokaryotes lack a cell nucleus (Margulis and Sagan, 2002).

> [laugh], it is a cell which is determined to respond to its environment and reproduce ... so if you have a change in the environment the bacterial cells or microbial cells will respond to that change. (Karen, scientist)

Karen senses that the ability to communicate could open the door to the possibility of granting microbes self-awareness therefore she limits this prospect by portraying microbes as simply responding to the environment, without considering that this description could be applied to all living beings. Although Karen recognises bacteria's awareness of others around them, she does not acknowledge the possibility of them being aware of themselves. Similarly, while molecular biologist Julia finds the idea of microbial self-awareness exhilarating, she uses the concepts of response and reflex to deny microbes of this possibility because, according to her, their communications does not contain a decision or free will, but is rather a determined response.

> There's evidence they can communicate with each other chemically ... but it's not, I don't think it's like a 'Ah, now let's go' ... it's just a physical response, it's like a, what's the word, reflex. (Julia, scientist)

In my endeavour to carry out this research in a recursive manner where each interview and observation informed the following, I brought microbiologists' uneasiness around self-awareness to the attention of Matt, cooperative horticulture teacher. Abstracting from the relevance of self-awareness, a possibility he does not see himself as knowledgeable enough to evaluate, Matt suggests that what truly matters is not whether microbes behave or react or whether they may be proved to indeed be sentient and have consciousness, but their value and membership to the soil community.

> We don't even need to think about whether they are self-aware if we just think that they have intrinsic value. ... You don't need to quantify it, you can say that, that matters as much as everything else ... equally to our concerns or needs. (Matt, horticulture teacher)

While Matt shifts the discussion from microbial self-awareness to an intrinsic value that does not require further 'proof' of mattering, I found acknowledging the argument around sentience in nonhumans and specifically in microbes useful here to

explain the consistent resistance of these microbiologists to engage with microbial behaviour. An increasing interest in the possibility that life forms such as plants may have cognitive functions induces philosophers Paco Calvo Garzón and Fred Keijzer to argue that 'plants can be considered to be minimally cognitive' (2009:249), while plant cell biologist František Baluška claims that 'plants also show active behavior, including kin and self/nonself recognition' (2009:viii). In terms of microbial sentience, as molecular microbial ecologist Chris tells me, scientists 'have been looking at spying, cooperation, all these sort of human behavioural traits or animal traits in microbes and they can find them' (Chris, scientist). Thus, alongside the description of microbes as unit, microbiologists employ contrasting metaphors, such as instances of microbial 'spying', 'cooperation' and 'cheats', showing that the metaphors able to connect with shared conventions and resemblances are not limited to deterministic understandings of the microbial. Furthermore, cognitive psychologist Arthur Reber argues in a rather straightforward manner not only that bacteria have consciousness and think, but also that '*sentience* is an inherent feature of living organic form(s)' (2019:x). A particular encounter with a caterpillar munching on Reber's basil leaves changed the way he considers animal consciousness, but in what he defines his 'precaterpillar days' he was part of the group of 'decliners' of these notions because he was concerned 'about seeming to embrace crazy ideas' (2019:xii). When talking to soil microbiologists about behaviour and witnessing their outright rejection of any intentionality in the microbial world, I am therefore reminded that 'decliners' of consciousness and self-awareness may be moved by fear of ridicule more than by conviction. Embracing these ideas could expose them not only to criticism within the scientific community but could also compromise their everyday interaction with colleagues in the lab. Thus, within the current soil microbiology discourse, a close relationship with microbes remains too sensitive to be taken seriously by soil microbiologists, unless they reach a microbial fascination and engagement, an event I explore in the following section.

Flipping it around: becoming with microbes

Despite having initially identified small scale growers as the unheard voice in the soil microbial field, as I proceeded with my fieldwork I found other 'minoritarian' actors across the range of expertise I studied. By minoritarian I refer to positions that do not represent the dominant instrumental approaches to the microbial communities, but that instead value microbial life intrinsically. In this sense, growers' ecological curiosity is also recognisable among equally sensitive soil microbiologists. As argued by Granjou and Phillips, the soil microbiome field is entangled with the possibilities for new relationships with the nonhuman rather than simply entailing a utilitarian position towards the microbial (2018). Alongside microbiologists who are comfortable with a technoscientific type of research that conceives microbial communities as instrumental to agricultural and sustainability agendas, attitudes I explored in chapter four, a number of other microbiologists seem to value microbial life in and for itself.

The possibility of forms of not human-centred interrelationships with microbes emerge among soil microbiologists who have admiration for the microbial world and who allow soil microbes to affect them. These scientists, moved by 'ecological curiosity' and 'fun' (Chris, scientist), show a stronger environmental and political awareness that allow them to establish their own personal connection with soil microbes. They hold an ethical commitment to changing soil practices beyond technological solutions and are open to more horizontal ways of relating to microbial life. Unlike the metaphors explored in the previous section, aimed at creating a distance from a microbe that lacks consciousness, the metaphors used by these scientists encourage a microbial closeness with the human domain. This shows once again how the soil microbiome field is a non-linear space where detached approaches coexist with stances, rooted in environmental and political awareness, that allow for microbes to be seen.

Grace, a molecular biologist, has a particular way to relate to the 'fascinating phenomenon' of symbiosis in place between plants and fungi and how their communication takes place (Grace, scientist). She recognises that this area 'becomes really quite easily anthropogenic' (I believe she means anthropomorphic) and she

dwells on the similarity between the plant/fungus 'very intimate relationship' and human relationships. Describing the communication between a plant and a fungus, Grace uses countless metaphors related to the human senses of talking, listening and speaking and she does so with apparent admiration. She translates plants' and fungi's voice by describing their communication in the first person and she strengthens the parallel with human behaviour by referring to this relationship as a 'dialogue' and a 'physical interaction' (Grace, scientist).

> We study how the plant is talking to the fungus and how it is listening to the fungus ... initially they both sit in the soil and don't know of each other and then eventually there's a chemical language spoken as they get into closer vicinity to one another ... which clearly announces 'Hey, it's me' right, so 'you're looking for' ... we actually even in science call this a very intimate relationship. (Grace, scientist)

Grace seems to enjoy humanising this encounter and is justified in this practice because it is carried out 'even in science'. Considering certain parasitic plants, Grace also calls them 'really bad guys parasitic plants' and refers to a particular fungus as 'a really good guy [laugh]' (Grace, scientist). The humanisation of these descriptions shows how studying symbiosis enables Grace to give invisible and nonhuman life a clear and intentional voice.

> It's actually a dialogue [laugh] ... the plant is shouting 'I'm here' ... we would say 'Go right, go left, go straight', in this case, you just follow the gradient to then quite successfully find the host root. ... the fungus releases a completely different set of compounds to now announce 'I'm coming' ... when the plant now perceives the presence of the fungus it needs to know it's the good fungus, 'I am not mounting a defence response', 'I'm not loading my gun but I'm actually opening the doors' ... it's if you wish the first committing step where they 'Ah' say 'Oh yeah', ... 'Yes', it's like a marriage [laugh]. (Grace, scientist)

Grace clearly considers the 'plant perspective' in engaging with the 'desirable partner' that is the fungus (Grace, scientist). Being an established professor, her

metaphors of fascination could be related to her frequent interviews with the press that require an attractive language to capture public attention. However, they also shows a deep admiration for the plant/fungi relationship that creates sensitivities and modes of relating beyond objective descriptions of microscopic life. Similarly, soil microbiologist Nicholas declares he is aware of microbes and 'feels' that they are alive, however because he is also a senior scientist used to explaining the field to non-experts, he may be attempting to provide an answer that satisfies the interviewer.

> I sort of visualise these things as living organism and I sort of have a feel for what's happening in these complicated communities, it's quite hard to visualise it, in terms of, you know real. But you have that sort of abstract feeling for the biology and the life and the things and part of that as a scientist is putting a name on these things like you would for your friends ... I know what they look like, I know, I get a feel for their habitat and what processes they might be going ... I definitely do sort of, have a feeling for them as living entities. (Nicholas, scientist)

Nicholas employs the odd parallel of naming friends, he can see microbes as living organisms and he knows what they look like, implying again that seeing is important in relating to living organisms. He defines this as an 'abstract' feeling that keeps him in an objective distance from his entity of study, in an attempt to find a harmonious position between 'feeling' for these communities and studying them objectively. Also early career researcher Emily has not forgotten that microbes are alive. She sees them as living beings and she talks about them with fascination in 'how they form kind of barriers, or armies against each other to outcompete other microbes' (Emily, scientist). Her use of neo-Darwinian metaphors of interaction and competition to describe microbial activity shows in this case a close relationship with microbes and does not contain the ambivalence present in other accounts because it is accompanied by microbial admiration.

> It's absolutely thinking about what they're doing and how they're interacting with each other and yeah they are small and you can't really visualise them very well but I suppose, I've seen lots of pictures of microbes so [laugh], ... it

really is kind of zooming right into the soil ... it's focusing right in on the microbes and kind of forgetting everything else. (Emily, scientist)

Figure 23: Zooming from soil…

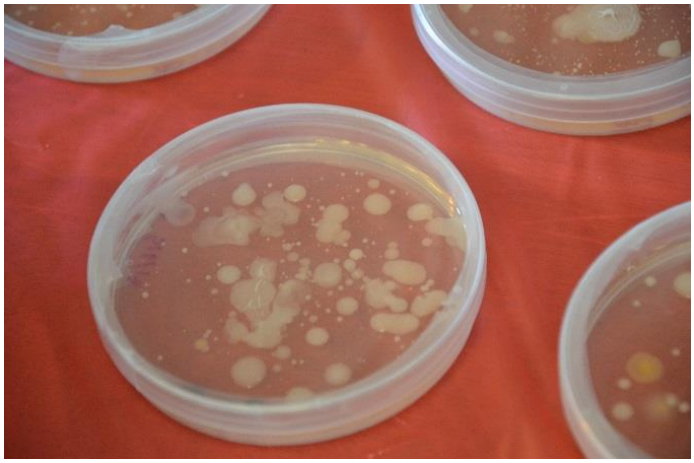

Figure 24: ...to microbes

While acknowledging microbes' small scale, Emily finds it effortless to 'zoom in'. She explains this easiness by referring to pictures of microbes she has seen, but I have the impression it is an admiration for them rather than the possibility to 'see' them that allows her closeness. For Emily, scale and invisibility do not entail a difficulty in relating to microbes but on the contrary, they allow her to ignore 'the insects, the beetles, the worms' (Emily, scientist), the more visible beings of the soil that Emily does not consider in her work. For her, studying microbes involves performing a close-up of the very inner core of the soil in order to focus on its most invisible and microscopic organisms. Unlike other early career researchers like Rachel, she is able to 'see' microbes and this ability is rooted in her strong environmental and political

convictions: ‘we need to realign our focus now to soil health and environmental health’ (Emily, scientist). Discussing her future career, Emily states that she will ‘definitely stay within soil. If not, then it’ll be with me in the allotment so [laugh], it will always be there somewhere [laugh]’ (Emily, scientist), thus showing how the depth of her connection with soil is independent from the forms that this relationship may take.

Because of her collaborations with clinicians and some work on antimicrobial resistance, Julia’s focus is more to do with how to protect herself from harmful microbes through ‘washing hands’ and making sure to have ‘a well-done burger [laugh]’ (Julia, scientist). In this sense, the invisibility of microbes translates into their harmful potential, an element that was marginal in my study, as the post-Pasteurian turn as proposed by Paxson (2008) emerged more strongly in the discussions with scientists. This shift is characterised by a collaborative attitude towards microbes that goes beyond strict safety regulation, to consider them as needed allies. While Julia seems for a moment to display strong Pasteurian understandings of the microbial, she also embraces the idea of humans being outnumbered by microbes because the awareness that there are ‘more microbial cells in my body than there are my own’ (Julia, scientist) can decrease human pride.

> I find that a little bit mind-blowing, still ... It’s amazing, it’s quite nice cause it puts us in a place a little bit because really, we’re just a host for microbes, cause we like to think that we can influence everything and we are very important but sometimes it’s quite nice to have a bit of a sanity check like this. (Julia, scientist)

Julia hints at the idea that we are not the only actors that ‘can influence’ and she is interested in a form of awareness about the microbial that can decentre anthropocentric descriptions. In the following excerpt she admits her own tendency to humanise microbes when drawing them, thus showing her ability to connect by giving them human features. She also has a fascination for how microbes look ‘on the inside’.

> I've drawn microbes with eyes ... I think we try to anthropomorphise everything including microbes ... I actually in my head seem to think of them more like an amoeba, but they're not. ... Another thing that I find fairly mind-blowing is how molecules go across the microbes ... I can't quite imagine, picture in my head what a microbial cell is like on the inside. (Julia, scientist)

Unlike other scientists mentioned in the previous section, Julia has a light-heartedness also about the idea of microbes as ancestors, showing that she seems open to this possibility: 'prokaryotes ... were the first living things, so everything came from them somehow [laugh] a very long, long time' (Julia, scientist). While Julia does not necessarily consider microbes as our predecessors, her arguments around a coevolution that should result in more respect for microbes implies a position that accepts a fragile boundary of the 'human', a human who is not seen as a unit but a fluid continuation from past evolutionary symbioses, an understanding in line with Margulis' invitation to consider the evolutionary role of microbes.

> They were here before we were and I imagine as soon as we were colonisable they were in there ... in many ways they've been around for much longer than we have so we should give them some more respect [laugh]. (Julia, scientist)

Chris, who is based at a research institute focused on environmental science, has an especially horizontal relationship with microbial life and something unusual to say about behaviour. He not only understands the implications of the word, but he shows a particular excitement around the topic: 'we constantly do talk in terms of behaviour' (Chris, scientist). He is aware of the ramifications of anthropomorphising microbes when talking about behaviour but nonetheless, like Grace, he gives them a voice, talks on their behalf and explains their point of view for instance when discussing what in his area is called 'life history strategies' and the presence of microbial 'cheats' who avoid the production of costly enzymes: 'they'll go "Oh, why do I have to invest in producing this costly compound, because everybody else is producing it?"' (Chris, scientist). Chris employs a humanising terminology especially when describing microbes with intentional characteristics such as 'spiteful behaviour' versus others who are 'slow growing, ... a lot more chilled out and they're sat there' (Chris, scientist).

> Bacteria can evolve ... if they're struggling, they can find a very quick way of dealing with that ... they like build up an army and then 'we switch on our rotting genes that are going to destroy the plant' ... I mean I don't know, behaviour, yeah they do have behaviour but it's again it's like sort of human, but then you could argue well yeah, we're just responding to things as well. (Chris, scientist)

While Chris starts talking about microbial behaviour in a rather enthusiastic way, in the course of the interview he seems to have a moment of hesitation in confronting its full implications. He however does not retreat and instead pushes things further by considering how humans also respond in similar ways. In this sense, unlike other soil microbiologists, Chris argues that humans simply respond to their environment like microbes. He then proposes a parallel with policy decisions that may not be predictable in the same way that microbial behaviour is uncertain, thus he directly compares humans and microbes in the unpredictability of both.

> Somebody might make a policy decision if they're just having a bad day, ... you need a really complicated economic and political model to predict what the humans would do ... there's certain things you can't predict and then you think well, yeah but that's the same for microbes, there's limits to what you can actually predict ... there's a realm of deviance that is just totally unpredictable and that extends to everything whether it's trying to understand microbial diversity or yeah, or human decisions. (Chris, scientist)

In an unusual ambiguity traversing policy and science, Chris sees forms of deviance in both microbial and human behaviour as a demonstration of their similarity in that they escape predictability. He seems to acknowledge John Law's depiction of the world as 'filled with currents, eddies, flows, vortices, unpredictable changes, storms, and with moments of lull and calm', a 'tide, flux, and general unpredictability' often impossible to map out (2004:7). Chris' parallel between humans and microbes means that he flips the question around in surprising ways by disputing whether humans behave. In arguing that humans are as unpredictable as microbes, Chris questions his own consciousness and what truly drives him.

> I'd put that on its head actually ... perversely flipping it around I see humans as microbes ... my consciousness is guided by other things, really, and it's actually quite peripheral, compared to my need to feed and reproduce ... the main part of what you do is fundamentally, is perhaps no different to that of a microbe, and you're just trying to optimise your environment ... If you come from it the other way do we see behaviour in humans? But I'm being a very cold scientist in saying that ... maybe it should be like the other way around, these forces exist and all the organisms show them to some extent, it's all, I guess it's all from DNA ... what DNA is up to and has this need to replicate and yeah it's, it can find amazing ways of keeping itself replicating and, whether that's in a bacteria or if it's in a human or, it will manage to do it [laugh]. (Chris, scientist)

In questioning whether humans truly behave, Chris takes the risk to appear 'cold', thus unlike Joseph who aligns scientists with robots, he does not consider lack of feelings as necessarily a valuable trait in his practice. Chris proposes to flip things around and look at it the other way, something that allows him to ask whether we see behaviour in humans. Thus, instead of extending a human ethics or consciousness to the microbial realm, for Chris the parallel human/microbe leads to a reduction of human free will and a more deterministic understanding of consciousness that is controlled by DNA. In a sense, by comparing humans and microbes, Chris chooses to diminish human consciousness instead of ascribing it to microbes. In this way Chris resorts to a form of genetic determinism where all actions of both humans and microbes are dictated by a genetic need to replicate. This use of biological metaphors to talk about the social world in deterministic terms coexists with the previously mentioned unpredictability, creating ambivalence in his account about human and microbial behaviour.

The interview with Chris was particularly useful because it allowed me to consider the possibilities of becoming affected by microbial life in ways I had not anticipated. It showed me that microbiologists are capable of engaging with soil microbial communities in direct and personal ways. How they relate to their object of study could be significant in rethinking the idea of objective science but also the already

discussed technoscientific approach of the field entailing the manipulation of microbial communities. Sensing or feeling microbes can entail a reconsideration of their lives as deserving respect. This is not to say that it would lead to an end of microbial experimentation, but it could involve a different relationship with microscopic life, not only in labs and growing sites but also in wider public spaces, where microbial communities could become relevant, respected and admired regardless of their size or invisibility. Ultimately it could entail a decentring of the human from a primacy position within the environment and in the association with other organisms.

As I have shown, Stengers' concept of ecology of practices in this context is a useful invitation to think about the possibilities of becoming something else through the interaction with each other (2005; 2010a; 2010b). Stengers suggests looking at forms of relating with different species that lead to different outcomes in making visible a neglected issue in the ecological debate (2010b). In this sense, asserting the possibilities of becoming means recognising that other forms of relating beyond microbial exploitation are available and present. Avoiding the erasure of an ecological discourse that prioritises the intrinsic value of soil invisible communities, the ecology of practices is not focused on the way things are but on what they can evolve into, in a transformation valuable when it leads to becoming something different, in touch with other life forms. An ecology of practices can assist in considering the relationship between sensitive soil microbiologists and their object of study, in the process of being altered by the meaningful encounter. This ecology of practices could raise the neglected microbial soil at the forefront of the ecological debate because what matters is that microorganisms 'have intrinsic value as living organisms' (Matt, horticulture teacher). The ability of microbially sensitive scientists like Chris to establish the value of microbial life in public debate can constitute a change, first in how they see the world and then in a related redirection of their practice, towards scientific questions that matter.

To the need for delivering the services of microbial communities in soil, Chris opposes his identity as one of 'those strange people in white coats that work on microbiome [who] say there's some benefit to some organism in the soil' (Chris, scientist). Thus

Chris and the 'microbiome people' emerge as minoritarian in their value for microbes, biodiversity and nature that they do not see as services nor they are willing to sell but instead they value intrinsically. Within what they perceive as a reduction of soil life to instrumental purposes, they dissociate themselves from the business, industrial or agricultural implications of soil microbial life. They acknowledge a connection with soil microbes and respect their aliveness to the point that microbes cease to be defined and start in turn defining their human investigator. In doing so, soil microbiologists like Chris who are 'always thinking about microbes' (Chris, scientist) allow themselves to 'feel' and 'become with' microbes in the way Haraway suggests when exploring what we are when we are in touch with other animals (2008), in a multispecies entanglement where we 'become-with each other' (2016:97). It is in this sense that the interview with Chris can be interpreted as a tale of kin because he 'flips things around' not only in defining humans and microbes, but in allowing himself to be deeply affected by microbial life. Alongside anthropomorphic verbal descriptions as well as enjoying fermented products, Chris relates to microbes through his relationship with the landscape. It is as if for Chris seeing microbes is not necessary to think about them in his daily life because they 'appear' through the landscape.

> From what I've done with microbes it's helped, it's made me think a lot more about the landscape, in a strange way, in a sort of roundabout way. (Chris, scientist)

This becoming with microbial companions emerges when Chris is 'out walking or riding my bike' and considers 'land management' (Chris, scientist). He notices the landscape and wonders 'oh that looks quite interesting, oh there has been a long term management change there and it doesn't appear to be a reason for it' and knows that 'it's causing a difference in my acidobacteria'[25] (Chris, scientist). Thus, unlike other scientists, Chris does not 'enjoy silent, unconscious relationships with microbes' (Margulis and Sagan, 2002:18) and instead acknowledges his interconnection with different microorganisms. Chris links this awareness back to

[25] A widespread strain of bacteria found particularly in soils (Kielak, et al., 2016)

where he is from, where he 'used to wake up to this patchwork on the side of a hill' and started wondering 'why does it look like that?', a question that led him to be involved in 'landscape surveys of microbes' and 'trying to build a model role to explain why we find microbes in different areas' (Chris, scientist). Implicitly alluding to a sense of scale and temporality, Chris' research on soil microbes is then strongly entangled with his place of origin, a place he mentions more than once with concern for the future of agricultural subsidies and what this will mean for its landscape. Becoming with microbes then is a lot more that being moved by his work, it is an association with the microbial that resonates with what for Chris is most precious. This becoming emerges when Chris sees humans as microbes and asks 'do we see behaviour in humans?'. Deliberately forcing the interpretation for a moment, I read this question as if also implying *apart from converting oxygen into carbon dioxide*, 'do we see behaviour in humans?' because Chris sees humans as microbes, thus in the same way he attributes them a deterministic urge to optimise their environment, he would ascribe them the performance of functions, ultimately rendering them microbial.

At first this becoming may seem willing, conceptual and political rather than a somatic and embodied entanglement proposed for instance by Natasha Myers' crystallographers (2015) or Vinciane Despret's horse-attuned human bodies (2004). But in the same way that 'modelers' bodies need not look anything like molecules to form a sympathetic relation with them' (Myers, 2015:110), so difference or invisibility need not be an impediment to somatic feelings of sympathy towards microbes among soil microbiologists. It is then possible to think that not only the microbes described by the scientists 'in tune' with them have been humanised, but that these scientists have themselves being rendered microbial 'bodily' as well as conceptually. By connecting with microbes through a walk or a bike ride, Chris is entangled with them at a somatic level. In drawing microbes with eyes and imagining them as amoebas, Julia has become with microbial companions through her drawing hand. Similarly, Emily is able to zoom into the microbes making the need to see them superfluous, while her relation with soil traverses fields from the lab to the allotment. Nicholas maintains an abstract feeling for these living entities that allows him to

identify microbes like naming friends. Finally, the close relationship Grace has developed with the symbiotic encounter between plants and fungi can be understood as a symbiosis itself, where Grace has now joined the symbiotic crowd.

In this sense, while throughout the thesis I have used the concept of entanglement primarily referring to the intertwined nature of a process or relation, I now treat this notion more precisely as indicating modes of relating that go beyond mere association, forming 'highly specific configurations' where relationalities take place without the need for proximity, to constitute the very being of entities that are not separated (Barad, 2007:74). It is through these relationships that 'people and things are moved about, and even transformed, as matters of affect' (Latimer and Miele, 2013:8) meaning that it is through a microbial entanglement that Chris now looks at the landscape in a new way that connects him back to his place of origin as well as to the invisible entities of his research, entities that have changed and transformed the way he sees the world. This is where from pure instrument of research microbes become participants 'in ways that affect the knowledge produced' thus escaping their mere utilitarian role (Latimer and Miele, 2013:24). Joanna Latimer and Mara Miele suggest to me the next questions: how do these entanglements affect knowledge production in the soil microbiome field and how to extend the ontology of the entanglement to the epistemology of knowledge? How is the now rendered microbial Chris affected in the actual questions he asks and in the creation of his scientific field? How overcoming the dualism human/microbe transforms the science? Chris is transformed and in turn transforms soil microbiome knowledge by introducing a political element in knowing that certain policy decisions 'will affect the microbes', that means for him asking questions from the microbial point of view: 'why are the humans using the land like that?' and 'why are the humans doing that when they could do that?' (Chris, scientist). It means looking at humans from a microbial standpoint that sees how unpredictable and deviant policy decisions affect 'us', the microbes.

Conclusion

In this chapter I have explored how soil microbiologists conceptualise and think about microbial life. I have considered how they struggle to 'see' microbes and remember that they exist, but also how they deliberately re-establish a separation from them. This distance emerges in microbiologists' strict delimitation of agency and consciousness to the human realm, contributing to a definition of microbes as unintentional entities. I have argued that in the soil field defining microbes also means shaping and reasserting the distinction between human and microbe. The function performed by these definitions becomes a strategy to establish boundaries between life and nonlife, free will and determinism, in the name of objectivity and scientific advances.

The word behaviour surfaces as significant in this context for its ability to demarcate human traits as distinct from microbial attributes. It shows the ways in which certain microbial characterisations employed by soil microbiologists are located in the liminal space between agency and predetermination. Once microbial behaviour is accepted, there is no guarantee that even more thorny concepts such as self-awareness and consciousness will not be taken into consideration. If microbes are allowed to behave, they may deserve more respect and a whole new discussion about sentience within soil microbiology and beyond. While opening a debate on microbial awareness may not entail the end of their manipulation, it could result in a reconsideration of the ethics of microbial research and the technoscientific approach of the field, posing a threat to the nonchalant exploitation of microbes. It may even involve facing the act of killing in the autoclave - rather than mere disposal. Conversely, avoiding the word behaviour means bypassing ethical complications so to allow the perpetuation of science as usual in the microbial technoscientific field. If microbes are defined as a mere cohort and what they do is constructed as a function, they become inanimate units determined by DNA and fit for research. Related to the metaphoric language used by microbiologists, the chapter has also explored the presence of an ambivalence where microbiologists who reject microbial behaviour at the same time tend to use anthropomorphic metaphors when describing microbial activities and circumstances. The attempt to strengthen the

human/microbe separation is therefore betrayed by the collateral effect of the very metaphors used by the scientists. Bringing to the scientific terrain the controversial word behaviour as well as other concepts such as self-awareness and ancestry, has proved a valuable prompt to explore the ambivalence of these definitions.

While engaging with the interrelation of life intended by Margulis and Haraway represents a minoritarian endeavour in this field, when the microbiome people allow themselves to 'see' and connect with microbes, to think about them means to feel and speak for them. It becomes an association that manifests both conceptually by questioning the solely human nature of free will (or the existence of free will at all) and bodily through bike rides, drawings, allotments, naming friends and symbiotic aggregations. Becoming with microbial companions means allowing to be changed, transformed and affected by soil microorganisms and to be rendered microbial. It means to alter in turn the scientific questions, to reconfigure human and microbe's identity and to eventually acknowledge, quoting the most microbial of my participants, that 'we're just responding to things as well' (Chris, scientist). For soil microbiologists it ultimately means to research soil microbes whilst caring for what they do. Thinking through Julia's drawing, Grace's congregations, Chris's rides, Emily's close-ups and Nicholas' identifications I hope to have shown how becoming with microbes is only a matter of allowing.

Chapter 7. Conclusion

Introduction

In this final chapter, I revisit and extend the main arguments and paths of enquiry proposed in the thesis: the contrasting versions of the future and the varying levels of technological interventions promoted in soil microbiome research; the ways in which this travelling knowledge touches the spaces it enters; the possibilities that relating to microbial life can offer to reimagine novel ways of becoming. By exploring the ways in which the soil microbiome is defined, known and managed across diverse domains, this thesis has suggested that listening to neglected matters is the question of sociology. In this future-oriented field, further sociological engagement is critical in continuing to disentangle the complex interconnections and co-productions of a multifaceted object of study. The thesis has thus proposed a case for considering, observing and breathing underground life and for paying attention to the unseen. In the current search for solutions to anthropogenic damage, invisibility can be a hindrance to the recognition of soil and microbes, but only for those who do not allow themselves to be attentive. Among the microbiome people, microbes are already witnessed and admired. To see the unseen, all it takes is to listen and take notice. It is then possible to affirm that microbes matter and that soil is not dirt. When those who think with microbes engage in bodily and imaginative ways in this more-than-species and multi-domain encounter, they can transform the way they see the world, affirming novel possibilities in the process of becoming more. Only then, microbes can truly be seen.

Future narratives

Like any other scientific endeavour, far from being a neutral project, the knowledge produced around the microbial communities of soil is driven by diverse and interconnected agendas. More than ever, soil is recognised as in urgent need of restoration. Detrimental intensive agricultural practices that rely on chemical fertilisers, monoculture, ploughing and pesticides are depleting the soil to what many observers consider a point of no return. Within ecological, policy and food debates,

there is a recognition that without immediate change, global harvests are numbered, with dire consequences for food security, livelihoods and the loss of biodiversity linked to unsustainable farming practices. The urgency of addressing anthropogenic environmental destruction and the need to ensure a stable and productive food system are considered to require immediate attention and practical solutions.

Soil microbiome research, the field of study concerned with the collective communities of trillions of microorganisms living in soil, poses itself as a possible solution to these pressing issues. Soil microbial communities associate with plant roots and have an impact on their growth, health and wellbeing. They provide nutrients and protect them from disease. In the context of an ecosystem services framework, the activities performed by the soil microbiome become provisions that can be exploited as a sustainable substitution to the use of chemical fertilisers and pesticides. As the agricultural use of these products can destroy certain groups of microbes decreasing the overall diversity of the community, this life form is constituted as both an organism in need of protection from destructive anthropogenic practices as well as a technological solution to depleted soils, provided it is manipulated for this purpose. Through various interventions and genetic engineering, microbial communities can be enhanced and 'unlocked' for the sake of human food. Their symbiotic relationships with certain families of plants can be extended to other crops, or they can be made into a 'soup' and inoculated into poor soils to improve plant productivity. Researchers studying the microbial communities of soil consider their management and exploitation the way forward to a sustainable food production no longer based on chemical use. They see microbial communities as critical in the search for solutions to eroded and depleted soils, decreased yields and shrinking biodiversity. The instrumental role assigned to these microbes contains an inevitable anthropocentric narrative focused on human needs. In this technoscientific mode of operating, microbial communities emerge at the boundary of life and nonlife, a mass of unidentifiable units only considered for the human purposes they serve.

Because of increasingly recognised anthropogenic devastation and damaging interventions that now need further technofixes, invisible entities living underground

are seen as offering a promising vision of the future. As I have explored in chapter four, while largely unknown both in terms of composition and functionality, the soil microbiome becomes associated with a promissory hope that relies on the expectations around technological innovations and manipulations. In a microbiopolitical narrative of management and control, there is a sense that while providing future solutions, microbial communities are currently not complete or enough as they are (and perhaps never will be). Their beneficial activity needs some enhancement and unblocking to be truly useful. In the present moment they do not work, but they *will* one day in the future. This narrative assumes that the next technology will be the one that works and that the next inoculant will be able to persist and benefit the soil. The present only holds possibilities and imagination, but it is in the future that the technology will show its benefits. Thus, soil microbiome research is a present endeavour, but oriented to the future, when the manipulations will offer those solutions currently unavailable. Producing this narrative, the soil microbiome field also promotes and justifies its own existence, because it is always in the future that the latest technology will solve the urgent problems at stake. It is future microbial technofixes that will correct previous innovations that now appear redundant and outdated and therefore need further interventions. This future is almost here, close enough to justify further funding, but adequately distant to provide researchers with work for decades to come.

Throughout the thesis I have also emphasised the discordant nature of the soil microbiome field across and within different communities of practice. Because of its interconnections with contested debates on food production, the future of agriculture and the environment, soil microbiome knowledge is constituted across the scientific, policy and growing realms as a nonlinear space where each argument has a counterargument, each claim can be dismissed and retorted, each proposal contains its direct opposite critique. Views around the solutions needed for a restoration of the environment and biodiversity are inevitably disputed. Microbial communities are then technologies but also living beings. They are solutions and friends, inanimate objects and fascinating creatures. The interventionist attitude and the optimism of those involved in powerful networks for the bioengineering of new

microbial technologies are confronted fiercely by those who reject this technological business. Policy experts, soil microbiologists and growers are not uniform groups driven by solutionist thinking. On the contrary, both within and across these practices, there is a sense that microbial communities of soil are valuable not uniquely for their instrumental and economic services but for their own sake. Experts of food policy invested in the development of a more sustainable food system are not convinced by high tech understandings of microbial life. In small growing sites, growers are becoming knowledgeable and interested in microbial communities, but they often reject a technofix based on microbial products. Even when they see microbes as beneficial for the work they do underground, their attitude can rarely be characterised as purely exploitative. Instead, their views emerge at times as an ethical commitment opposed to a productionist and anthropocentric narrative that perpetuates the exploitation of natural resources.

These views too are oriented to the future, but drawing from the past, from traditional ways of growing and engaging with food that offer new modes of thinking about the future as slow, where soil and its produce acquire meaning aside from being seen as a mere growing medium and a product. This future vision is concerned with re-establishing lost relations with what is most precious, a knowledge that has been annihilated by plastic, supermarkets and high tech. This imagined future suggests growing food in a way that respects natural resources, is in tune with the long term pace of soil formation and involves the local community. It is a future that reconsiders the meaning of food, no longer seen as the current inexpensive commodity but as a knowledge that contains a precious sense of citizenship. This future includes slow technologies that reconnect people and land, rejecting mediating fast instruments that render food growing a cold productionist endeavour. This is a future where small, local projects engage with the community and with the science that matters, a science that recognises the interconnection of all life and the importance of small and invisible organisms. While at times these ideas verge on romanticism, I have shown how they also contain ethical and political ambitions that reject conservative nostalgia. It is this version of the future, a future that does not dismiss the past but is grounded in the present need to restore more meaningful

relationships with soil and its life, that this thesis has witnessed, detected and affirmed as possible.

A moving object

Throughout the thesis I have argued that soil microbiome knowledge circulates across sites, leaving the scientific laboratory to enter and be transformed by other domains. As I followed my multifaceted object of study through knowledge spaces, I was able to learn that regardless of the varying degree of understanding of the microbial communities, this invisible life emerges as important and in need of attention across different forms of expertise and ways of knowing. In small scale, organic growing sites, the life of microbes is understood as valuable and beneficial. This awareness does not entail a general endorsement of the scientific project but is located at the boundary of respect, admiration and contempt for authoritative ways of knowing that are often seen as detached from soil. For growers, an authentic connection with soil needs both a physical and a figurative proximity that includes touching the soil, observing, bending down to tend and listen to the plants. These ways of knowing are signifiers of a truly direct connection with the land in an endeavour that includes the engagement of human communities in the process of food growing. Unlike the soil employed for what these practitioners see as possibly dubious purposes in laboratories removed from the agricultural land, the soil touched in growing sites is felt as a proximate soil connected to an ethics of change, thus to a project worth pursuing. To be appreciated in the growing realm, the knowing of microbial communities needs to become a sensorial and an embodied way of relating that requires the senses. Thus, when soil microbiome knowledge enters agricultural fields, for the growers it becomes a worthy knowledge and practice representing for once the value of science, in an exception to what the growers consider the problematic endeavour of lab-based knowledge.

With government agendas focusing on soil and its neglected invisible life, this moving object of study also affirms its presence in policy debates. However, the translation of this knowledge from object of scientific enquiry to policy recommendation

emerges as rather complicated. Different priorities and understandings of the purpose of knowledge means that the process of translation becomes an unfaithful fabrication of a message now simplified and rendered meaningless. Because soil microbiome research is a novel and complex field still carrying many uncertainties, it does not appear to lend itself to straightforward application. As this research is often publicly funded, soil microbiologists recognise and respect the need to render the field available for policy and public debate, but they consider the oversimplification embedded in the process of translation a problematic devaluation of their work. Furthermore, they feel an untenable pressure to simplify their complex research into a business language they find foreign if not despicable in nature. When discussing these debates in chapter five, I have not dismissed policy claims, showing instead the reasonableness of experts who are invested in change in soil practices and who claim that only by translating this knowledge into bullet point policy briefings, it can be able to illuminate society.

I have also noted how similar dynamics are at work when engaging publics in the dissemination of this knowledge. In a recognition that often finds microbiologists and policy experts in agreement, the field's lack of appeal emerges strongly as a hindrance in capturing people's attention and involving publics. Unlike pandas, dolphins or pretty flowers, microbes are seen as a hard sell. They are invisible and complex entities that do not attract public interest. The neglect of soil in public debates and its association with dirt only add to the indifference and inattention surrounding the field. While the public emerges in the discussion with scientists and policy experts as a uniform entity that lacks interest in life forms not aesthetically attractive, I have also highlighted the willingness of soil microbiologists to 'get the message out' and engage people in a topic they consider worthwhile and unique.

Seeing the unseen: affirming the possible

Because the scientific project is epistemologically constructed around objective experimentation and a detached relationship between researcher and object of study, because of the routine and specificity of laboratory work, because of microbes' small scale, their short life cycles and the lack of individuality, because of all these

elements, soil microbiologists show some resistance in recognising a relationship with the microbes they study. At stake are concepts of agency and self-awareness, epitomised by the term 'behaviour' that the microbiologists tend to downplay or dismiss altogether in the microbial domain. As I have shown in chapter six, scientific metaphors are critical in the functions they perform and the particular perceptions they convey. The idea that microbes behave may grant microbes the capacity to act with intention or even to sense themselves and others. By carefully adopting metaphors that describe microbes as 'reacting' or 'answering to a stress', soil microbiologists are able to convey and reinforce a non-intentional conception of microbes. The transformation of microbial communities into entities without purpose is instrumental in constituting a detached relationship between microbiologists and the microbes they study. In this sense, while they research living beings, microbiologists constitute microbes in their daily work as somehow not truly alive.

As with other elements I have observed throughout the thesis, however, this too was to prove a nonlinear aspect characterising the soil microbiome field. Exploring more carefully scientists' discomfort around the word behaviour, I was also able to notice that the kinds of decentred relations I was interested in proposing were already in a process of becoming. While my interest in symbiotic theories of life predates the start of my fieldwork, I did not expect to witness the deep human/microbe entanglements I found especially among microbiologists. Their accounts allow for an understanding of the human as an organism enmeshed in fluid boundaries and past and present microbial interconnections. One of the main contributions of this thesis is then to have brought 'into existence, … in the very act of describing practices' issues 'detected at the same time as they are produced' (Stengers, 2010a:57). By listening to soil microbiologists in the precise moment they truly relate to microbes and recount their significant microbial encounters, I could detect the entanglements when they occurred, thus affirming what was always possible. It is through these moments of reaching out to microbes, of creating a possibility that seems new but was always there, that this thesis affirms the existence of relations not ruled by anthropocentric inclinations but defined by the ability to be influenced and

transformed by another life form, another species, another kin. Guided by the microbiome people, I could appreciate that a multispecies encounter does not even need to involve the same taxonomic order, but it can traverse biological domains. This multi-domain companionship does not require proximity if it can be envisioned and then intentionally embodied. It is this somatic entanglement with the unseen that leads scientists to be changed and in turn transform the questions they ask through a novel microbially informed perspective. In detecting this mingling I hope to have continued a path towards the recognition of the politics of microbial mattering.

In light of these arguments, I have a final observation on the role of invisibility in complicating encounters across kind. While some of the soil microbiologists I interviewed were keen on pointing out that microbes can be seen through a microscope, microbes are invisible to most people. Soil too, while visible matter, resides underfoot and is often addressed as dirt, thus sharing with microbes a still pervasive public disregard. However, what I learnt through my participants is that invisibility is a hindrance only for those who do not pay close attention. For individuals and communities of soil microbiologists, growers, policy experts, cooperatives and collectives keen on social change in an environmental sense and who share a respect for natural processes, microbes and soils have always been visible and recognised. Despite the neglect of the field, in the current awakening of soil as living, those who care to see are affirming the value of this life for itself in agricultural and ecological debates, in short they are becoming with microbes.

Further directions for novel entanglements

Because this thesis deals with expert knowledge, it has not involved publics. Publics transversally emerge as stakeholders in the formation of the soil microbiome field as both supporters and receivers of scientific expertise, but they have not been given a direct voice. This is in line with my intent to explore the ways in which microbiome knowledge travels, shapes and is in turn transformed across expert spaces, thus with my focus on expertise. However, listening to the heterogeneous experiences and attitudes of different publics in regard to the emergence and development of the soil

microbiome field would contribute to illustrate their role in its establishment. Grounding the reflections on the blurry boundaries of the scientific and social sphere, these voices could offer insights on the role of the non-experts in the constitution of a primarily scientific object of study.

This is particularly significant in the current pandemic context whose wide-ranging social and economic repercussions elicit a question around future developments in post-Pasteurian understandings of microbial life, based on the assumption that microorganisms are not harmful but useful allies. It would be critical to examine whether this stance suffers a public setback and reverts to more fearful attitudes based on microbes' adverse potential for human health and if this turn extends to the soil realm. A return to a view of microbial life in purely harmful terms may entail a potential anthropocentric amplification that shrinks even further the possibility of a decentred recognition of soil microbial communities. But even more important is to consider whether the dichotomy of microbes as harmful or allies may be where the problem lies. As I have shown throughout the thesis, by questioning the boundary between humans and microbes that needs constant management and policing in order to avoid human humiliation, it is possible to move beyond the divide and embrace more attentive and respectful relations. Rather than an unceasing shift between dangerous and friendly characterisations of microbial communities, the affirmation of an ancient and still continuing entanglement between human and microbial life can result in more careful listening and becoming involved beyond our own human self.

Following the movements of soil microbiome knowledge, an often blurry object of study, has not been a straightforward undertaking. While the visual data has assisted me in thinking transversally, what I was following rarely appeared directly in my photos. It emerged instead through objects standing in various sites. These became elements to reflect upon, in their 'out of placeness' where microscopes inhabit growing sites and plants grow in labs. The challenge of locating my object of study was intrinsic in the resolution to chase the knowledge about microbial communities rather than the communities themselves. This inevitably has led to a form of exclusion and absence of the life form to which I call attention throughout the thesis.

As a result, I have not said a great deal about what microbes living in soil actually do, how they spend their time or, as bioinformatician Joseph would say, what they have been thinking all day. Despite the relevance of these questions, in order to displace and decentre the human from its exceptionalism, I have considered the exploration of the knowledge and practice it produces about the microbiome as the most urgent and critical endeavour.

Future valuable contributions to sociological research would therefore include attempts to explore soil microbial communities rather than focus on the mediation of the human knowledge produced about them. Here, I am not thinking about behavioural studies but rather about multi-domain explorations of entanglements and interconnections, engaging with microbes through tools and methodologies that are already available to social scientists, such as embodied forms of knowing. These could include ways to research microbes more directly through the involvement of the senses like the olfactory exploration of the microbially produced scent of soil or the observation of nitrogen root nodules that microbes generate when in symbiosis with leguminous plants. A fascinating, if controversial, field to pursue, suggested by one of the microbiologists I interviewed, concerns the study of microbial 'cheats', games and peculiar behaviours. In light of the arguments raised in chapter six around the discomfort most microbiologists display when confronted with the concept of microbial behaviour, exploring this specific area would provide a compelling contrast, perhaps leading the way for the affirmation of further human/microbe entanglements in even more visionary terms than the ones considered in this thesis. However the observation in laboratory settings would still entail the mediating element of 'the scientist', therefore implying once again the study of the knowledge rather than the microbial communities themselves.

The enquiries that inform this thesis, around the ways in which the soil microbiome is constituted across knowledge spaces and the different practices and expertise co-producing the microbial communities of soil as entities worthy of attention, allow me to propose the possibility for a sociology that becomes proximate to microbial life. In observing the coming to matter of the soil microbiome and interrogating what kinds of relations with microbes are possible, I have detected and witnessed

transformative forms of entanglements that are not only attainable, but already present among those involved with microbial life. Furthermore, by identifying a human-centric and technoscientific element in the study of the microbial communities of soil, I have joined others in showing that the social sciences and sociology in particular are capable of offering an important critique to the manipulative and exploitative ways in which scientific research approaches microbial life. Continuing on the path to detect these aspects and question a mere ecosystem service approach in the study of the microbial life of soil and beyond, is therefore the important task for a sociology that counters the anthropocentrism at its foundation as well as in wider social relations.

Considering my initial premise around the contribution of this thesis to a different sociology that includes, and is transformed by, the encounter with other-than-human lives, the ramifications of researching microbial knowledge for sociological approaches elicit more questions than they answer. What kind of sociology emerges through this encounter? Which new stories can be told? This thesis has shown that researching microbes and the knowledge about them - and therefore the human itself - requires types of engagements that affirm rather than merely witness new ways of relating. Microbial stories can be told by embracing definitions like those proposed by the biologist Margulis, who contrasts 'fallacious' competition narratives only able to dichotomise, with more accurate metaphors such as those referring to ecological relations (Margulis and Sagan, 2002:16).

My research findings allow me to affirm a disciplinary turn towards relationalities and encounters not only beyond an anthropocentric sociology but also alongside the attention to visible nonhumans. In the current interest in human/nonhuman relations that focuses on visible beings, a sociology that think with microbes requires to believe 'our eyes to have microscopic vision' (Hird, 2009:21). Considering the agenda for future sociological research, this thesis therefore presents a discipline that comes into real proximity with the invisible. It is possible to think and become with soil microbes, if sociology ceases to be intimidated by neglected entities and abandons the self-certainty of centrality and exceptionality. The discipline can then move and stand closer to life forms so far disregarded. This shift demands sociology

to follow objects of research that may not respond to abstract social criteria and may not look 'sociological', thus requiring a justification to more dominant disciplinary approaches. Far from ignoring the category 'human', this move is about questioning and interrogating new relations and intersections between and within species and entities not previously taken into account.

A sociology that questions who the anthropocentric 'we' includes is a discipline that listens to different stories with protagonists beyond and after the human. This involvement demands a form of humbleness that paradoxically entails audacity. The 'we' that engages other life forms such as soil microbial communities is the plural pronoun used by one of the microbiologists I interviewed when speaking directly for and with microbes, as shown in the previous chapter. The multitude 'we' he employs does not merely include microbes from a self-appointed spokesperson viewpoint, but is a plural voice that switches the microbiologist's angle from human to microbe, now embodying and personifying a community that includes visible and invisible beings. In a process of becoming with microbe, 'we' emerges as the effect of a multi-domain encounter between two formerly separated entities, the scientist and the microbe, now inextricably entangled. Learning about these associations, influences and interconnections is the main contribution my research and findings offer in making the microbial a life that matters and inviting sociology to move beyond anthropocentrism. Far from abstract representations and symbolism, this thesis shows how the discipline can affirm social life as constituted by a myriad of actors and forms of relating. Sociology emerges as a field of study engaged in muddy soil encounters with real organic beings, where entanglements are told outside of the domination of the scientific gaze and through an involvement with soil and its dwellers. Nonhumans are then allowed to arise, without the requirement for a symmetry of treatment but with the respect due to the 'other', now seen as a concrete microbial presence grounded in the depth of soil and undergoing material alterations and renewals. In this 'sociology of the mud', where exceptionality is detected in other organisms beyond the human, microbes, plants and other entities are active in the production of knowledge. *Man* is decentred to make room for other 'others'. The peripheral becomes central, the invisible is now seen. A sociology that

questions and leaves human exceptionalism behind involves telling the tale of collectives learnt through proximity with soil microbes, thus making the microbial a life that counts. A sociology able to tell a different story, a tale of kin, is a discipline that allows the interconnection of life to be affirmed without re-proposing a hierarchy of difference where a marginalised group excludes the other. A sociology affected by microbes, the discipline I have proposed in this thesis, does not lead to a disregard of other 'others', but to an extension of the horizon of careful listening.

Appendix A: Information Sheet

PARTICIPANT INFORMATION LEAFLET

Study Title: Humans, microbes and soils: A microbial ethnography

Investigator: **Serena Zanzu**

Introduction
You are invited to take part in a research study. Before you decide, you need to understand why the research is being done and what it would involve for you. Please take the time to read the following information carefully. Talk to others about the study if you wish.

(Part 1 tells you the purpose of the study and what will happen to you if you take part. Part 2 gives you more detailed information about the conduct of the study)

Please ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

PART 1

What is the study about?

This study explores the practice and expertise involved in soil microbiology in order to extend a conversation on the intersections between the social and life science.

Do I have to take part?

It is entirely up to you to decide. I will describe the study and go through this information sheet, which I will give you to keep. If you choose to participate, I will ask you to sign a consent form to confirm that you have agreed to take part. You will be free to withdraw at any time, without giving a reason and this will not affect you or your circumstances in any way.

What will happen to me if I take part?

We will do an interview that will take no longer than an hour. The interview will be audio recorded.

What are the possible disadvantages, side effects, risks, and/or discomforts of taking part in this study?

While any risk or disadvantage is unlikely to occur as a result of your participation in this study, should you experience any discomfort, we will stop the interview and you can withdraw your participation from the study.

What are the possible benefits of taking part in this study?

It is hoped that this study will open the possibility for a conversation across different forms of expertise in soil microbiology.

Expenses and payments

Taking part in the study does not entail any reimbursement or payment to the participant.

What will happen when the study ends?

When the study ends, the interview data will be deposited at the ESRC archive who will treat it according to data protection regulation. The researcher will delete the data five years after completion.

Will my taking part be kept confidential?

Yes. I will follow strict ethical and legal practice and all information about you will be handled in confidence. Further details are included in Part 2.

What if there is a problem?

Any complaint about the way you have been dealt with during the study or any possible harm that you might suffer will be addressed. Detailed information is given in Part 2.

This concludes Part 1.

If the information in Part 1 has interested you and you are considering participation, please read the additional information in Part 2 before making any decision.

PART 2

Who is organising and funding the study?

The study is funded by the Economic and Social Research Council (ESRC).

What will happen if I don't want to carry on being part of the study?

Participation in this study is entirely voluntary. Refusal to participate will not affect you in any way. If you decide to take part in the study, you will need to sign a consent form, which states that you have given your consent to participate. If you agree to participate, you may

nevertheless withdraw from the study at any time without affecting you in any way. You have the right to withdraw from the study completely and decline any further contact by study staff after you withdraw.

What if there is a problem?

This study is covered by the University of Warwick's insurance and indemnity cover. If you have an issue, please contact the Chief Investigator of the study:
Serena Zanzu (T: +44xxx; E: x@xx)

Who should I contact if I wish to make a complaint?

Any complaint about the way you have been dealt with during the study or any possible harm you might have suffered will be addressed. Please address your complaint to the person below, who is a senior University of Warwick official entirely independent of this study:

Director of Delivery Assurance
Registrar's Office
University House
University of Warwick
Coventry
CV4 8UW
Complaints@Warwick.ac.uk
024 7657 4774

Will my taking part be kept confidential?

Yes. The interview recording and transcripts will not include the participant's real name. This will be substituted by a pseudonym from the data collection stage onwards so that at no point the two will be associated. The data will be stored on password protected hardware. Access to the data will be restricted to the researcher, the supervisor and the ESRC archive after the completion of the study.

What will happen to the results of the study?

Interested participants will be able to access their own interview transcripts and a non-technical summary of the research. The results of the study will be published as a PhD thesis and related journal publications.

Who has reviewed the study?

This study has been reviewed and given favourable opinion by the University of Warwick's Humanities and Social Science Research Ethics Committee (HSSREC).

What if I want more information about the study?

If you have any questions about any aspect of the study, or your participation in it, not answered by this participant information leaflet, please contact:
Serena Zanzu (T: +44xxx; E: x@xx)
Supervisor: Lynne Pettinger (T: +44xxx; E: x@xx)
Supervisor: Maria Puig de la Bellacasa (T: +44xxx; E: x@xx)

Thank you for taking the time to read this participant information leaflet.

Appendix B: Consent Form

HUMANITIES AND SOCIAL SCIENCE ETHICS COMMITTEE CONSENT FORM

Title of Project: Humans, microbes and soils: A microbial ethnography

Name of Researcher: Serena Zanzu

Supervisors: Lynne Pettinger (T: +44xxx; E: x@xx); Maria Puig de la Bellacasa (T: +44xxx; E: x@xx)

Project information: This project explores the practice and expertise of soil microbiology in order to extend a conversation on the intersections between the social and life sciences. The data collected in these interviews will be used in connection to a PhD thesis and related publications. Participants' names will be anonymised. This project is funded by the Economic and Social Research Council (ESRC).

Please initial all boxes

1. I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. ☐

3. I agree to take part in the above study. ☐

4. I agree to the audio recording of this interview. ☐

_____	_____	_____
Name of Participant	Date	Signature
_____	_____	_____
Name of Person taking consent	Date	Signature

Appendix C: List of Field Sites

Ethnographic observation

Organic food growing worker cooperative (6 months volunteer work)

Lab visits

Agricultural research centre
Environmental research centre
University plant science and food security facility
University growing room

Growing site visits

Organic farm
City farm
Growers cooperative
Urban growing space (cooperative development agency)
Mixed dairy/crop farm (hosting university research unit)

Events attended

Homeacres open day, Somerset, September 2019
Superbugs: The fight for our lives, Science Museum London, April 2019
Charles Dowding: No-dig gardening, Oxford Allotment Association, November 2018
We feed the world, Bargehouse Gallery London, October 2018
Soil: Our buried treasure, Royal Society, July 2018
Open farm day, Sonning Farm, June 2018
*Food system resilience: Concepts and practis*e, IFSTAL Webinar, March 2018
Wonderful woodchip!, Tolhurst Organic, February 2018
Innovation in the microbiome, King's College, February 2018
Sustainable diets for all, Tim Lang IFSTAL Public Lecture, December 2017
Bioart and bacteria exhibition, Oxford Museum of the History of Science, October 2017
Crick symposium germfree / Microbiota topics, Francis Crick Institute, May 2017
The microbiome and human health, Society for Applied Microbiology, April 2017
'Resistance', Birkbeck College Science Week, April 2017
The role of the microbiome in gastrointestinal cancers, Imperial College, March 2017
London microbiome meeting, St Thomas' Hospital, January 2017

Appendix D: List of Pseudonymised Interviewees[26]

Scientists (17)

University 1
Rachel, early career researcher
Nicholas, professor of environmental microbiology
Caroline, professor of entomology

University 2
Emily, early career researcher
Deborah, early career researcher
Anthony, bioinformatician

University 3
Grace, professor and head of symbiosis group

University 4
Joseph, bioinformatician

University 5
Harry, nutrition and agriculture scientist

University 6
Julia, molecular biologist

Research Centre 1
Karen, molecular microbial ecologist
Chris, molecular microbial ecologist

Research Centre 2
Isabel, molecular soil ecologist
Margaret, agricultural microbiologist
Ben, plant and soil microbiologist
Owen, soil scientist
Jack, molecular microbiologist and bioinformatician

Growers and cooperative workers (7)

Organic farm
Neil, grower

Worker cooperative
Peter, grower
Matt, horticulture teacher

[26] Not in overall interviewing order.

City farm

Alice, grower

Growers cooperative

David, grower
Alex, grower

Urban growing space (cooperative development agency)

Steve, grower

Policy experts (6)

Daniel, policy manager (microbiology institution)
Andrew, professor of food and health policy (university)
Kevin, communication officer (soil programme)
Lisa, director of research strategy and policy (university)
Fiona, professor of global food and agricultural policy (university) and former leader of nutrition policy (international organisation)
Naomi, CEO (cooperative development agency) and chair (food board)

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