TRUFFLE CROPS AND SOIL DRUGS: NEW FUNGAL PRACTICES AND EPISTEMOLOGIES FOR THE 21ST CENTURY

by

Peter Gibbs Oviatt

Master of Arts
The New School for Social Research, 2013

Bachelor of Arts
Baruch College, 2008

Submitted to the Program in Science, Technology, and Society
in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in History, Anthropology, and Science, Technology and Society
at the
Massachusetts Institute of Technology

September 2019

Signature redacted

Signature of Author: ______________
History, Anthropology, and Science, Technology and Society
August 20, 2019

Signature redacted

Certified by: ______________
Heather Paxson
William R. Kenan, Jr. Professor of Anthropology
Thesis Supervisor

Certified by: Signature redacted

Stefan Helmreich
Elting E. Morison Professor of Anthropology
Thesis Committee Member

Certified by: Signature redacted

Christine J. Walley
Professor of Anthropology
Thesis Committee Member

Accepted by: Signature redacted

Tanalís Padilla
Associate Professor, History
Director of Graduate Studies, History, Anthropology, and STS

Accepted by: Signature redacted

Jennifer S. Light
Professor of Science, Technology, and Society
Professor of Urban Studies and Planning
Department Head, Program in Science, Technology, & Society

TRUFFLE CROPS AND SOIL DRUGS: NEW FUNGAL PRACTICES AND EPISTEMOLOGIES FOR THE 21ST CENTURY

by
Peter Oviatt

Submitted to the Program in Science, Technology, and Society on August 30, 2019 in
Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in
History, Anthropology, and Science, Technology and Society at the
Massachusetts Institute of Technology

ABSTRACT

Perigord truffles (*Tuber melanosporum*) have, over the past 200 years, become a cultivated crop grown across the globe. Since the 1890s, soil microbes have been commodified to "fertilize" agricultural crops (and are now referred to as biofertilizers, biostimulants, or simply "soil drugs"). This dissertation examines both truffle crops and soil drugs to investigate how a beneficial relationship between plant roots and fungi has become meaningful in twenty-first-century industrial societies. This fungus-root connection, which exists with over eighty percent of plant species, is called the mycorrhizal symbiosis. I draw on ethnographic research centered in Corvallis, Oregon, and Dijon, France to show how mycorrhizal practitioners (from foragers and farmers to laboratory researchers and industry boosters) have struggled against the biological constraints of the mycorrhizal symbiosis and have combined agronomic and agrarian epistemologies to develop a diverse suite of "sustainable" land management practices that promise "symbiotic efficiencies." In truffle farming, this has resulted in an ethic of professionalization (with "best practice" guidelines), and a desire for what Anna Tsing has called "scale making." At the same time, a contrasting ethos of "engaged waiting" guides a subset of truffle farmers who continue to steward agrarian ecologies by remaining attuned to a wide array of life forms and extended time frames. In the biofertilizer industry, mycorrhizal science has given rise to numerous methods for producing mycorrhizal inoculants, or soil drugs. Following the work of Christopher Henke, I discuss how mycorrhizal inoculants are poised to bring about two forms of repair to soil ecologies and industrial agriculture: maintenance and transformation. With both truffle farming and the mycorrhizal biofertilizer industry, I examine the challenges and controversies surrounding the efficacy of emergent mycorrhizal practices, testing claims about ecological restoration, universal standards of practice, and the role of farm consultants. A recent wave of mycorrhizal science employs experimental systems that look beyond a singular fungus-root pair to consider broad and indeterminate communities of fungi, bacteria, and plants; this new science critiques the use of commercial inoculants in favor of reformed agricultural practice (from plant breeding to tillage regimes) that directly consider the role of soil symbionts.

Thesis Supervisor: Heather Paxson
Title: William R. Kenan, Jr. Professor of Anthropology

ACKNOWLEDGEMENTS

In 2017, I co-organized a panel for the American Anthropological Association Annual Meeting with Joanna Steinhardt, which we called "the Mushroom Multiple." Practice around the mycorrhizal symbiosis, the subject of this dissertation, is likewise multiple. As such, there are many different communities of mycorrhizal practice to which I am indebted for this completion of this dissertation. Executives of agricultural conglomerates, enterprising farmers, struggling commercial truffle foragers, and retired amateur mycologists all welcomed me into their work spaces and taught me about the values that arise from thinking and acting across plant, animal, and fungal categories.

Toward the beginning of my dissertation research, my education in fungal biology included visits to the Hibbett lab at Clark University, participation in the weekly lab meetings of the Pringle Lab at Harvard University, as well as regular exchanges with the rotating cast of international mycologists who work with Don Pfister, mycologist and curator of the Farlow Library and Herbarium. On mushroom collecting and taxonomy, I am indebted to members of the Boston Mycological Club (BMC), in particular my dear friend Jason Karakehian with whom I went on many mushroom foraging adventures, cultured fungi in the lab, and combed through documents within the Farlow and BMC archives. Librarians at the Farlow were likewise generous with their time in pulling out countless documents on fungi and mycological figures.

In Oregon, a long list of mycorrhizal experts welcomed me into their lives and work. For over half a century, Jim Trappe has been at the center of a diverse set of mycorrhizal practitioners that includes farmers, researchers, and industrialists across the Pacific Northwest and as far away as Australia. Jim was instrumental in connecting me with such figures, and was generous in sharing his knowledge not only of truffles and forest mycology, but his even deeper insights into the human condition. In providing a place for me and my family to sleep while in Corvallis our conversations knew no limits. Jim, and his extended family—Efren, Matt and Kim, all of whom work with fungi in various capacities—have felt like family of the best kind, those with whom you can enjoy hours over Oregon's endless array of heavily hopped ales. I have similar gratitude for the many individuals who have come and gone from the study of mycology and mycorrhizal science in Western Oregon. I met with these individuals in cafes for food and drink, in labs to look at fungi and equipment, in forests to hunt truffles, and at scientific conferences from Mexico to France. They include: Michael Amaranthus, Randy Molina, David Pilz, Scot Loring, Charles Lefevre, Tom Michaels, Dan Luoma and Joyce Eberhart, Steve Carpenter, Shannon Berch, Wang Yun, Michael Castellano, Jane Smith, Carlos Colinas, Amy Rossman, Joey Spatafora, Bob Linderman, Paul Schreiner, Carolyn Scagel, Jeffrey Stone, Elaine Ingham, Matthew Slaughter, Rebecca McClain, Neil Anderson, and Ted St. John. These researchers have held a variety of positions managing and laboring in labs at Oregon State University and the USDA Forest Service, and as owners and employees of mycorrhizal companies from British Columbia to California. Through these individuals I met with other researchers who were extremely generous with their time, notably André Fortin in Quebec, and Jesús Pérez Moreno and Roberto Garibay Orijel in Texcoco and Mexico City respectively.

My relationships with over a dozen Oregon farmers—of truffle and plant crops—have proven equally rewarding and educational. Most would prefer to remain nameless, but I will give special mention to Pat Long, Simon and Linnet Cartwright, Colin Morris, Burkhart Ledeboer and Bogdan Caceu, all of whom welcomed me on their farms and shared their know-how and approach to life and truffles.

Charles Lefevre and Leslie Scott provided the opportunity to present my research at the Oregon Truffle Festival, an event which remains central to Oregon's truffle industry.

A diverse array of dogs and dog handlers provided the time and willingness to show me how to hunt truffles, both during their training in city parks and backyards and professionally in Oregon's forests and truffle orchards. A few names include Jeannine May, Alana McGee, Kris Jacobson and Ilsa. I hold extra gratitude for Marilyn Richen, Tammy Jackson, Gucci and Blue for meeting with me across Northern and Southern Oregon.

Most commercial truffle foragers with whom I spoke would prefer to remain anonymous, but I will call attention to Eric Jones, Toby Esthay, Jason, and Eric L. who readily met and openly provided information on commercial truffling in Oregon.

Frank Evans, Pat Rawlinson, and Matt Trappe are just a few of the members of the North American Truffling Society (NATS) who shared truffling locations and truffling documents.

Toby Primbs and Jim LeComte helped me navigate state regulatory measures as they relate to truffle hunting and bio-fertilizers.

In France, I am indebted to many who hold joint appointments with public universities and with research centers of France's National Institute for Agricultural Research (INRA) in Dijon, Nancy, Toulouse, and Mirecourt. A woefully incomplete list of those to thank includes Daniel Wipf, Pierre-Emmanuel Courty, Dirk Redecker, Diederik Van-Tuinen, Leonardo Casieri, Philippe Lemanceau, Francois Le Tacon, Claude Murat, Francis Martin, Christophe Robin, Guillaume Becard, Christophe Roux, Florence Hellec, Juliette Anglade, and Thomas Puech. Truffle technicians who provided assistance and time include Pierre Sourzat, Pierre Tabouret, and employees at AgriTruffe. I am grateful to those in the political world of the French truffle industry (truffle growers' associations, government offices), including Christine Dupaty and her lovely family, as well as Jean-Charles Savignac, both of whom invited me to their homes, their truffle orchards, and with whom I enjoyed unforgettable truffled meals. I also benefited from the generosity of figures such as Damien Berlureau, who work across the truffle worlds of politicians, growers, truffle-tree nursery owners. Damien is an all around booster of truffle production, in France and beyond.

I am likewise indebted to truffle technicians, researchers and politicians in Umbria, Italy. With Matteo Bencivenga, Domizia Donnini, Andrea Rubini, Francesco Paolocci, and Gabriella Di Massimo I visited Italian labs and farms. I thank Zach Nowak, Elisa Ascione, and others at the Umbra Institute for connecting me with an array of individuals in Italy's rich food industry, as well as for providing me with a beautiful location in Perugia in which to write. Across France and Italy my interactions with truffle growers were limited to one or a few farm visits. I give a collective thank you to the dozens of individuals with whom I met.

Through exchanges of ideas and many revisions of papers in varying degrees of completeness, an array of scholars and scholarly communities made this dissertation possible. My greatest thanks goes to Heather Paxson, who has served as far more than official advisor throughout my time at MIT. Heather has been diligent with tasks ranging from conference and teaching logistics to grant writing to data analysis and theory-building. Above all, she has become a supportive friend. The same gratitude goes to my dissertation committee members Stefan Helmreich and Chris Walley, as well as other professors at MIT, including Harriet Ritvo, Rosalind Williams, Michael Fischer, and Clapperton Mavhunga, who have read various iterations of the writing that has made it into this dissertation. Likewise I thank the broader community of students in MIT's HASTS program, many of whom have read messy article drafts and provided invaluable feedback. Further inspiration has come from the MIT students whom I have had the pleasure of teaching.

Groups who have read previous iterations of pieces of this dissertation include those in Heather Paxson's Art, Craft & Science graduate seminar, members of the Multispecies Reading Group led by Stefan Helmreich, the Martin Family Society of Fellows for Sustainability, participants of the Northeast STS conference (NESTS), the Critical Metabolism Working Group in NYC, the Constructing Scientific Communities workshop held in Cambridge, Massachusetts and London, as well as those anthropologists, science studies scholars, and environmental historians who provided feedback at an array of scholarly conferences. Many administrators and librarians made all of these exchanges possible. Particular thanks goes to Karen Gardner, Irene Hartford, Amberly Steward, and Michelle Baildon.

Finally, none of this would have been possible were it not for Jamie, my partner in all facets of life. Jamie pushed me to bring our collective love for mushrooms to an academic level. She has continued to inspire my thoughts and clarify my writing ever since. My parents have not wavered in their support as my interest in food and environment led me to volunteer in Cameroon, conduct research in India and China, work in kitchens from San Francisco to Manhattan, and finally begin a PhD program. Brian and Joyce, my beloved in-laws, have been equally supportive, and have provided a space in beautiful Southern Oregon that became a refuge for many months of dissertation-writing that was filled with wildlife and carefully planned childcare. Oksana, who was born in Portland, Oregon where Jamie and I lived for a portion of dissertation fieldwork, has known nothing but a life in and out of airports, and an endless string of Airbnb rentals from Mexico to Europe. Not yet three, Oksana has a nose for truffles and an eye for mushrooms. It is thanks to Oksana and Jamie, the two ladies of my life, that I was able to find enjoyment as a doctoral student.

TABLE OF CONTENTS

INTRODUCTION

Industrialized societies in the twenty-first century are marked by a broad awareness of environmental ills that play out on local and global scales. The political and technological optimism that reached a pinnacle in the postwar period (see, respectively, Fukuyama 1989; Borlaug 1971) waned with the close of the twentieth century, and with the closure of many regional industries. In some cases, factories that underpinned entire communities closed overnight, leaving a toxic legacy that is proving to last generations (Walley 2013). An environmentalist movement picked up steam in the final quarter of the twentieth century (Davies 2013) amidst increases in the environmental ramifications of industrialism and the use of fossil fuels. By century's end, general publics were aware (if not supportive) of environmentalist issues. Broader consideration for the health of not just single organisms but relationships *across* humans and nonhumans fueled the nascent discipline of ecology—a term that came to name a political project as much as a field of research.[1] Concerns about environmental harm have entered the business plans and marketing departments of companies that continue to supply the products that decimate life forms and forms of life (Helmreich 2009). This decimation of nonhuman lives and of human cultures has been particularly severe in agriculture.[2] Within agriculture and beyond, a particular branch of ecological thought has become popular among

---

[1] The discipline of ecology has roots in imperialism, as islands in the Southern Hemisphere became colonies of European countries as well as experimental settings (Grove 1995; Anker 2001). The discipline, however, did not blossom until the latter half of the twentieth century (Worster 1994).

[2] For impacts to farm workers and agro-biodiversity, see Nash (2006), Altieri (1995), and Shiva (1993). For the decimation of agrarian communities in the United States, see Barlett (1993) and Berry (1996). For impacts of industrialized farming on French farming communities, see Cornu et al. (2018).

scientific and lay circles alike: symbiosis, or the concept that two organisms that live in proximity may benefit each other.[3] Although symbiosis has existed as a biological concept since the late nineteenth century, only in the past few decades has it become a potent symbol of ecology and environmentalism. If we consider that a few decades ago the general community of biologists viewed this concept as anomalous to life on Earth, and that this same community now agrees that symbiotic associations are critical to most any ecology and organism (Yong 2016), we can begin to see how the concept of symbiosis might beckon new soil practices that promise to be "natural," "eco-friendly" or otherwise desirable. I argue that recent (or renewed) attention to soil symbionts has brought new prescriptions for how soils *should* be worked, and even new perceptions on what soils *are*.[4]

Against such a backdrop of political ecology (Peet et al. 2011)—one inflected by a concern for the shifting epistemic meaning of symbiosis[5]—I investigate a symbiosis that is ubiquitous to soil ecologies. *Mycorrhiza* (literally, fungus-root) names an association that exists between mycorrhizal fungi and the roots of more than eighty percent of plant species. The fungus translocates soil minerals and water to plant roots in exchange for photosynthesized sugars. The fungal component of the symbiosis can be categorized into two primary groups: *ectomycorrhizal fungi* that visibly coat root tips and create macro fruiting bodies such as mushrooms and truffles, and *arbuscular mycorrhizal fungi* (AM fungi), which lack root coatings and do not form

---

[3] Symbiosis exists on a spectrum, from mutualism (both parties benefit fully) to parasitism (one party may not benefit, and may even experience harm). There are also varying degrees of reliance on the symbiosis, from facultative symbiosis (both organisms can live on their own) to obligate symbionts (an organism relies on its host for survival).

[4] For contrasting views on how the recent wave of attention given to soil symbionts (might) turn into new soil practices, if not new soil ontologies, see Granjou and Phillips (2018) and de la Bellacasa (2015).

[5] The political ecology with which I engage hinges on shifting values and epistemologies of the concept and symbolism of symbiosis. Considering that the definition and meaning of symbiosis changes so drastically, we might look at symbiosis as a "keyword" in the tradition of Raymond Williams (1985). For an overview of the disciplines of political ecology, see Robbins (2012). For an example (within the field of climate science) of how scientific facts and concepts change as they move across different communities, see Callison (2014).

mushrooms.[6] The first half of this dissertation concerns ectomycorrhizal fungi, which concentrate in forested landscapes; the second half concerns AM fungi, which concentrate in grasslands and arable soilscapes.

The four chapters of the dissertation feature four practices with the mycorrhizal symbiosis. These practices are undertaken by amateurs who forage for truffles, biologists who culture fungi in petri dishes, farmers who enhance mycorrhizal communities via crop rotations, and employees at the world's largest agricultural companies who market mycorrhizal fungi, among others. I turn to mycorrhizal practices—what people *do* with the symbiosis, with what tools, aims, funding, epistemologies, and in what contexts—so as to reveal the economic *value* and ethical and cultural *values* (Graeber 2013) that now constitute the symbiosis; this is to ask what "mycorrhiza" means (and can bring) to twenty-first-century environments and societies.

I argue that mycorrhizal value(s) have emerged with a rising interest in symbiosis. Scientifically, symbiosis has moved from the exception to the norm in ecological and evolutionary thought; in popular culture symbiosis has become the latest concept through which to nurture an awe for nature and build respect not just for organisms but for their relationships. In terms of soil practices, this rising awareness of symbiosis dovetails with a now half-century-old critique of chemical- and mineral-based products that have attended to the immediate physiological needs of plants, at the cost of greater soil ecologies (including the human cultures that produce and purchase what industry insiders call soil "inputs"). In response to Donna Haraway's call to "stay with the trouble" (2016), I keep my focus on a reductive and

---

[6] Instead of forming a sheath around root-tips, which serve as a point of nutrient and water exchange between plant and fungus, AM fungi grow into deeper layers of the root to build arbuscules which serve as points of plant-fungus exchange. AM fungi account for over seventy percent of all mycorrhizal fungi. For more on other types of mycorrhizal fungi, and for examples of fungi that blur these categories (e.g. ectendomycorrhiza), see Smith and Read (2008).

instrumentalist view of the natural world that has brought great profits to many industries—agriculture is no exception. I stay with a rather mechanistic logic that takes its metaphors from thermodynamics (inputs and outputs; systems) and applies them to indeterminate and unbounded soilscapes. This is a logic that sees soilscapes as zones—if not built infrastructures—for which those inputs (that will bring the greatest profit for companies by being the most potent across varied soilscapes) are singled out and mass-produced. To focus on mycorrhizal practices—efforts to manage the symbiosis for the production of plants or mushrooms—is to focus on the tension caused by bringing a complex and multi-species symbiosis into a reductive form of agriculture and soil management. I show how mycorrhizal practices at once uphold reductivist logics and practices of land management, while they also challenge this paradigm, potentially being a catalyst for a new way of thinking about, working and dwelling within soilscapes.

This dissertation offers an anthropology of mycorrhiza, which I position between an anthropology of biology and biotechnology (Helmreich 2009; Fortun 2008; Soto Laveaga 2009; Lock 2002) and an anthropology of agriculture and food production (Terrio 2000; Paxson 2013; Lien 2015; Wurgaft 2019). Rather than provide, or critically review, a "natural history" concerned with the biology and physiology of mycorrhizal fungi, I look at how socio-cultural meaning is folded into natural phenomena. In doing so, I uphold a nature-culture distinction to the extent that it remains important to the scientists, amateur mycologists, and farmers with whom I conducted ethnographic research. Put differently, I look at how "naturecultures" (Haraway 2003) shape what a largely microscopic process such as the mycorrhizal symbiosis comes to be (cf. Latour 1988).

I discuss the biology of fungi and the ecology of mycorrhiza in the service of explaining how and why specific communities of practice and agricultural economies extract meaning from the symbiosis—and how they succeed or are prevented from manipulating mycorrhizae for particular ends. This is indeed a dissertation about the *instrumentalization* of fungi. With the exception of truffle foraging, my focus is on people who strive to make fungi do different things. Although I engage with literatures that feature "multi-species" ethnographic work (Kirksey and Helmreich 2010) or "posthuman" analytical frameworks (Wolfe 2010), what follows is not so much a narrative that "de-centers" the human, or asks after the agency of humans and non-humans, so as to rework parliaments of *actors* and *actants* (Latour and Porter 1993). Rather, my concern lies with how the symbiosis has become important—and has taken on a singular multiplicity (Mol 2002)—depending on specific communities of practice and their understandings and experiences with the fungus, its associates, markets, and settings (landscapes or laboratories).[7]

By taking up mycorrhizal research and practices carried out in contrasting sites and locales, from Oregon to France, the dissertation demonstrates how soilscapes and experimental settings constitute the symbiosis just as much as any particular species or practice. This emphasis on landscape and setting informs questions of scale. I engage with a body of literature that reaches into multiple disciplines—cultural geography, rural sociology, anthropology, and science and technology studies—to analyze how products, practices and their epistemologies homogenize, and become hegemonic, as they move across time and space, what Anna Tsing

---

[7] Ultimately, the reader will decide if this dissertation "de-centers" the human enough to qualify as a "post-humanist" work. Throughout the dissertation, I focus on how humans give value(s) to fungi, and manipulate and use them for what are, foremost, anthropocentric ends. Following a dichotomy in which non-human life is separated by its "instrumentalist" or "intrinsic" worth (see de la Bellacasa 2017; Kloor 2015), this dissertation covers the former category. I describe fungi from the human's point of view (how could it be otherwise?). This involves the employment of mycorrhizal science while simultaneously analyzing this science. Following scholars in science studies, such as Donna Haraway (1997), I do not find the use and analysis of a science to be contradictory. Along with Haraway, I seek to contort linear narratives in which rational humans gain more and more "control" over nature, typically via a scientific methodology. In this way, my dissertation joins a rich literature that provides description and analysis of how human and nonhuman agencies are "mangled" in laboratories (Pickering 1995) and in an array of agrarian "domestications" (Cassidy and Mullin 2007; Pollan 2001).

(2000) has called “scale making.”[8] But “scaling up” is not all bad. Thomas Lyson (2008) advocates a “civic agriculture,” one that is “of the middle,” or comprised of mid-sized farms that can support a family’s livelihood while building an agrarian community—all amidst a backdrop in which large-scale factory farms (Fitzgerald 2003) have come to set new standards in yields, the distribution of products, and the dynamics of agricultural commodity markets.[9] Similarly, a 2018 special issue of the journal *Culture, Agriculture, Food and Environment* is dedicated to the topic of “agri-cultures of the middle,” which contributing authors take to be an important constituency of farmers, yet one that has been given short shrift by social researchers, public administrators, and agronomists alike. Kathryn De Master (2018), in the introductory article to the special issue, defines “mid-sized” as farms unable to achieve industrial economies of scale and to use the distribution channels available to farms of thousands of acres; however, they are also too big and too commoditized (or so perceived) to win the support of proponents of “alternative” agriculture, who often valorize “smallness” in size. De Master argues that these farms are critical to well-functioning agrarian communities and economies. I seek to analyze this mid-level by detailing mycorrhizal practices, such as truffle cultivation methods and the production of mycorrhizal inoculants, as they are made for farms of increasing scale, and brought to larger communities of practice.

I argue that a dual movement is behind efforts to scale and commercialize mycorrhizal practices and products. On the one hand is a flattening of local difference: for example, when boosters of AMF inoculants claim that the AMF communities already present in arable lands are unable to bring symbiotic efficiencies, this encourages the use of only a few types of AMF

---

[8] In later work, Tsing and others discuss “conversion devices” used to flatten or erase local particularities, see Bear et al. (2015); on how space is active and facilitates the movement of various forms of capital across time and space, see Smith (1984).

[9] I also look at mid-level practices of truffle foraging and soil management beyond agrarian settings.

inoculants in soils across the globe. Truffle orchard consultants also try to flatten regional differences (to the extent possible) by traveling the world to give advice to farmers in regions and on soils with which the consultant is hardly familiar. On the other hand, many of these same boosters of AMF inoculants or of truffle farming make appeals for local land stewardship and for the enhancement of regional biodiversity. In short, mycorrhizal industries do not only adhere to what David Harvey (1990) has described as the time-space compression of materials, cultures, and political economy under conditions of late capitalism. They also exemplify a contrary movement: the local particularities flattened in the name of better flows of capital (money, life forms, knowledge) also become *phenomena to exploit*—the very qualities that give value(s) to certain "bio-objects" and "green" industries (Vermeulen et al. 2012).

The framework of *ecologies of production* helps me capture this tension between the context-specific and the desire to make truffle or plant production more context-independent. Heather Paxson (2013) uses the concept of ecologies of production to discuss the aggregation of factors required for the production of artisanal cheese in the United States. These factors include the microbes in ruminant guts and the ambient environment in which cheeses mature, pastoral landscapes, pasteurization machinery, food safety regulations, and tax breaks given to agrarian entrepreneurs. I identify similarly complex and dynamic ecologies of production for culinary truffles and mycorrhizal inoculants packaged as agricultural fertilizer. Boosters of truffle farming turn to romanticized images of truffle orchards—with symbiotic trees, trained dogs, and skilled farmers—to promote the industry. Meanwhile, investors of a new paradigm of industrial agriculture—BioAg—now ground their promises in an *in vitro* (near sterile) system of production that can churn out contaminant-free inoculants cheaply and at increasing scale. These investors create value for BioAg by positioning it as an answer to the environmental destruction caused by chemical agricultural fertilizers. These mycorrhizal commodities are not only examples of "disaster capitalism" (Klein 2007), or "accumulation by restoration" (Huff and Brock 2017). They are also generative sources of "bio-capital," a capitalist value tied to the biological sciences that scholars have documented across a wide array of agricultural and biomedical industries (Sunder-Rajan 2012; Ritvo 1995; Birch and Tyfield 2013; Cooper 2008). Mycorrhizal applications, I argue, carry symbio-values, a branch of bio-capital that latches onto the current environmentalist and epistemic cachet of mycorrhiza. Symbio-values are tied up with epistemologies and cultural values (inclusive of the agronomic and the agrarian; scientific, agrarian and lay forms of knowing) that have burgeoned around the biological and ecological concept of "symbiosis."

Historical Background and Epistemic Context

An inescapable biological fact shapes any mycorrhizal practice: *fungi cannot make their own food.* So how do fungi eat? Until recently, biology textbooks and popular accounts highlighted two ways: fungi can be pathogens, meaning they take nutrients from other living organisms, often killing the organism in the process; or fungi can be decomposers, meaning they feed via external stomachs that excrete powerful enzymes that break down recalcitrant organic compounds (lignin and cellulose) into digestible forms. Only in the past few decades has a third means for fungi to feed entered mainstream consciousness: through a symbiotic relationship with plant life. Lichens, an association between fungi and algae is one example; another is the mycorrhizal symbiosis, which, depending on nuanced and layered environmental conditions, wavers between mutualism and parasitism.[10] Addressing the question of why the mycorrhizal

---

[10] Fungi that can form lichen exist across a wide phylogenetic breadth of kingdom fungi; rarely can these fungi survive without their photosynthesizing associate, which can include algae and cyanobacteria. This conversation on how fungi obtain food calls for a larger point: fungi are nothing if not plastic. Depending on context, fungi can mix

symbiosis was ignored (if not rejected) by popular, industrial, environmental, and scientific communities up until the late twentieth century—as well as the form and nature of the attention the symbiosis finally did receive—provides a throughline of socio-historical context for the four ethnographic cases of mycorrhizal practice taken up in this dissertation.

Coining Mycorrhiza

In Germany, in 1885, Albert Bernhard Frank coined the term mycorrhiza.[11] Frank contributed to the science of plant-microbe interactions by combining two talents: an ability to synthesize and draw out patterns from a wide and fragmented body of research, and an ability as an astute observer and iconoclastic thinker willing to go against the traditional science on tree roots and forested ecologies, which, for example, viewed microbial attachments to tree roots as inconsequential to tree health, and, by and large, pathogenic. Frank came late in a list of naturalists who described how roots connect with a class of soil microbes; nor was he the first to identify that this connection is fungal in nature (Trappe 2005). Frank's creative insight came with his observation of the ubiquity of the relationship, which led to a declaration that was revolutionary among naturalists: not only was the relationship commonplace, it was common among *healthy* trees. Mycorrhiza did not indicate competition between tree and fungus, but rather cooperation (*ibid.*). Frank did not come to this conclusion by working in a void. Other naturalists whose work centered on fungi may not have been thinking about cooperation, but Frank's colleagues—including de Bary and Haeckel, who brought the terms symbiosis and

---

and mingle categories of fungal eating. Some species form a mycorrhizal symbiosis while producing enzymes that allow them to eat dead organic matter (Martin 2015). In some cases, mycorrhizal fungi end up weakening or killing their host. Some mycorrhizal fungi can survive indefinitely without associating with a plant; others, such as AM fungi are "obligate symbionts" and rely on a plant host for survival.

[11] Frank was a proponent of Schwendener's (1869) theory that lichens are a combination of fungi with algae. In 1877 Frank coined a term for this association, "symbiotism." Two years later de Bary (1879) used the word "symbiosis," and is known today as the author of the term.

(o)ecology to biology—certainly were. Frank thus came to understand and outline the ecology of mycorrhiza not by individual (or individualistic) inspiration alone, but rather as part of what Ludwig Fleck (1981) would call a "thought collective."

Frank's theory of a ubiquitous symbiosis, a view of soil ecologies in which cooperation and not competition is the norm, was poorly timed. This was the late nineteenth century, when Darwinian views of nature-red-in-tooth-and-claw won the day. This was Malthusian philosophy, which emerged from overcrowded nineteenth-century British industrial cities, brought to all of the natural world. The reigning ideology of nature at the time had it that resources are scarce and the *natural* way to proceed and to *select* winners and losers was through competition among individual organisms (Worster 1994). Today, evolutionary biologists try to incorporate the widespread occurrence of symbiosis into their models by upgrading the unit of natural selection from the individual to symbiont-host pairs or holobionts (Simon et al. 2019). Such theoretical frameworks, controversial still today, were far beyond the thought collectives of those men of science who collected and described plants and fungi in the nineteenth and twentieth centuries (Sapp 1994).

Symbiosis as a conceptual framework in biology did, however, thrive in those societies whose political and economic systems retained a philosophy and ethics of cooperation and association—Soviet Russia, and to a lesser degree France. In France, Peter Kropotkin's *Mutual Aid* (1915), which argued that mutualism is commonplace in ecology, evolutionary biology and human nature, was widely read and translated into several European languages. Shared across these same networks was the work of Russian botanist Konstantin Mereschkowski, who published articles on symbiogenesis, the idea that organelles such as mitochondria and chloroplasts were free living prokaryotes before a sudden evolutionary moment in which they became a heritable component of the eukaryotic cell— an evolutionary process colloquially described as *ingestion without digestion* (Margulis 1994). Not until the 1970s did Lynn Margulis began experiments to substantiate the theory of symbiogenesis with microbiological tools; she spearheaded an effort to popularize the theory among communities of biologists in the United States and Western Europe. Arguing that symbiosis played such a large evolutionary role was an uphill battle given the mainstream thought collectives in the biological sciences—especially that of neo-Darwinists—who were resistant to change.[12] The counter-cultural movement that arose in the 1960s in the U.S. and much of Europe, which would impact and populate a later generation of researchers (see Elaine Ingham, Chapter 4), contributed to this cultural shift in the biological sciences (Margulis 2012).

Culinary truffles are what brought A.B. Frank to study mycorrhiza. In the latter half of the nineteenth century Frank was asked by the King of Prussia to find a way to cultivate the tasty fungi. In the mid-nineteenth century, researchers were not convinced that truffles, or any mushroom that was frequently found next to trees, relied on any plant for its growth. Researchers debated over "direct" and "indirect" theories on how truffles might be cultivated; the direct methods left out the plant (the tree, in this case), while the indirect method attempted cultivation by going through the plant (Delmas 1983). Frank labored within the indirect method, but he did not succeed.[13]

---

[12] Margulis famously debated with Richard Dawkins on the role of symbiosis in evolution (Margulis 2012). Dawkins, who self-identified as a neo-Darwinist, promoted a "gene's eye view" of evolution; he famously called all organisms "lumbering robots" designed to protect and propagate genes (Dawkins 2016). It was hard for Dawkins to fit into the selfish gene framework widespread cooperation across organisms that are not phylogenetically related.

[13] Another false start for mycorrhizal applications, which gave twentieth-century American and British biologists a bad taste for mycorrhizal research concerns the work of Sir Albert Howard. Desperate to find a means or material by which he could prove the efficacy of compost as a form of plant fertilizer (to replace the chemical solutions that took agronomy by storm in the first half of the twentieth century), Howard turned to mycorrhizal fungi as the reason why compost was better for plants than chemical minerals such as nitrates and phosphates alone (Gieryn 1999b). However, when other researchers showed that mycorrhizal spores (and other propagules) cannot survive the heat of

Ironically, debates among Europe's top savants on whether truffles could be grown via direct or indirect methods occurred alongside the undeniable successes in truffle cultivation in an agrarian context. At least since the second decade of the nineteenth century, peasants in the South of France could demonstrate, via simple and concrete methods, how to farm at least one species of truffle: *Tuber melanosporum*. To researchers, the problem was that the peasants could not describe the mechanics behind these methods. When peasants could not even describe mycelium, or had a theory that countered fungal biology of the day, their farming methods were also written off by researchers (Rousseau 1866). But the success coming from the South of France was undeniable. With hundreds of tons produced a year, for over half a century, researchers could not sustain claims that the truffles would have grown naturally, without the aid of a farmer. That agrarian communities had methods to farm truffles became even more apparent following the two World Wars. In the postwar period, with the destruction of farming landscapes and the dispersal of agrarian communities, the national production of melanosporum dropped from thousands of tons annually to dozens.

In the postwar period in France, truffle associations formed so as to promote truffle farming and cobble together techniques for truffle orchard maintenance that had been lost and fragmented with the World Wars. Researchers at INRA created "truffle trees," seedlings with roots inoculated with melanosporum and free of competing fungi. Tens of thousands of truffle trees were planted across France, but still, melanosporum production never rebounded to pre-World-War levels. However, with truffle trees and orchard management techniques widely

---

composting, Howard was ridiculed and mycorrhiza became the "unwanted friend" of microbiologists (quoted in Koide and Mosse 2004).

available, the Meditteranean fungus became a crop elsewhere in the world, in locations where winters do not entail deep freezes, soils are well-draining, and water is available.

Overview of Chapters

The dissertation is divided into two halves. The first half addresses the foraging and farming of truffles. In these first two chapters, I show how a feeling for fungi builds in those who develop a connection with the underground fruiting bodies of mycorrhizal fungi. The latter two chapters discuss fungal inoculants that are used as biofertilizers, or "soil drugs." I discuss how "bio" products and practices are framed as something of and in the future, and how they gain value when judged against their chemical counterparts. I then detail the rise of AMF inoculants and a more recent wave of mycorrhizal science that places more hope for a future sustainable agriculture on reformed agricultural practices, rather than new lines of soil drugs.

Part I: Truffles

Chapter 1 examines the role wild truffles have played in promoting both public and scientific understanding of the mycorrhizal symbiosis. In the 1970s, young mycorrhizal researchers who wanted to bring knowledge of the symbiosis and its importance to forest health to the applied discipline of forestry were frustrated that work with the symbiosis largely was written off as unimportant.[14] I describe how the thrill of the truffle hunt became an effective tool to "infect" both professional biologists and those with no training in the sciences with enthusiasm for the symbiosis. This chapter traces the formation of a Pacific Northwest truffling culture that mixes

---

[14] I heard such accounts from now retired researchers at INRA who became leaders in the field of silviculture and soil science, for instance Jean Garbaye and Francois Le Tacon. I was told similar stories from mycorrhizal researchers in the United States, such as James Trappe, Robert Linderman, Michael Castellano, and Michael Amaranthus.

all segments of society—from self-described "tycoons" in Santa Rosa, California to mechanics and firefighters; those without a high school degree and those with doctorates. This expansive group formed around the foraging of truffles that are native to the Pacific Northwest, notably one with gustatorial qualities reminiscent of the famed Italian White truffle from Piedmont. The species, *Tuber gibbosum*, became known as the Oregon White truffle.

Through the hunt for the Oregon White truffle—as well as other species that are new to science—I describe the development of a *feeling for the fungus*. This phrase is borrowed from Evelyn Fox Keller's (1983) account of how the geneticist Barbara McClintock's devotion to the *whole* of the organism (in this case the maize plant) allowed her to make breakthroughs on chromosomal behavior only decades later identified by molecular biologists who follow a more reductive experimental approach. This incredible ability to endure, and even enjoy, extended durations of studying the whole organism so as to build up a knowledge of its molecular components was what McClintock called gaining a "feeling for the organism." I describe a similar phenomenon at play with trufflers in Western Oregon, who gain a feeling not just for the fungus but also for the symbiosis and for the broader landscape.

The chapter ends with a change in culture, in which the attraction to truffles is less about the process of learning how to hunt and more about the end product. The new truffle culture, I argue, has a greater concern for showing off one's relationship (via truffle-hunting dogs and truffle-producing orchards) to a culinary truffle whose cachet continues to grow within a global scene of gourmands. This may be an effective way of spreading an awareness for truffles, and perhaps the ecologies from which they come; but it comes at a price: it puts the earlier Oregon truffling culture at risk by short-circuiting the process that has allowed trufflers to develop a feeling for the fungus.

Chapter 2 turns from truffle foraging to truffle farming. It opens with a description of Pat Long, the first farmer in Oregon to grow successive crops of melanosporum. Long heard about the possibility of producing truffle trees and realized that his farmland outside of Corvallis lay near the 45th parallel—the same latitude as Southern France and melanosporum's native habitat. Long is a second-career farmer who has a style of engaging with his truffle orchard that involves adaptive tinkering and extended experimentation, a mode of truffle farming that I call *engaged waiting*. Engaged waiting is an iterative process of tinkering that may be slow to bring consistent truffle yields, but provides ample personal satisfaction for farmers who have the luxury of not depending on truffles for their livelihood.

As with Chapter 1, which describes the arrival of a new truffle culture, Chapter 2 traces how a new style of engagement arose, one that overlaps with but more so stands in contrast to an embodied form of knowledge acquisition, as gained through engaged waiting and extended periods of trial and error. The new approach to truffle farming involves a professional ethic that does away with the frugality of avoiding expensive machinery and orchard inputs—practices which helped build an image of truffle farming as sustainable and even as a means of enhancing biodiversity. Instead, driven by a desire to build a consistent, even standardized, and reputable regional industry of melanosporum production, this new approach turns to the latest machinery and a new class of truffle orchard consultants who come from regions such as the Sarrion Plateau in Spain and Manjimup, Australia, where melanosporum production is a thriving industry.

Chapter 2 introduces a theme that continues in the remainder of the dissertation: When it comes to managing the mycorrhizal symbiosis for practical ends, such as producing culinary truffles or growing plants with fewer petrochemical-based products, a reductive scientific approach may be necessary but is not sufficient. For nearly two hundred years, the success of select truffle farmers has perplexed truffle researchers. I argue that mycorrhizal management, such as truffle farming, is best served by using a collaborative approach in which agrarian and agronomic methods are treated with parity. I make the same case in the latter half of the dissertation, when practitioners turn to mycorrhiza to bring what researchers call "symbiotic efficiencies" to agricultural systems large and small, from the industrial and fossil-fuel based to the infrastructurally alternative.

Part II: Soil Drugs

Chapter 3 concerns the transformation of symbiotic microbes into an inoculant form—a soil drug— that can be used within industrial agricultural systems. I start off not with AM fungi, but with a group of bacteria called rhizobia that associate with leguminous plants. In the late nineteenth century, amidst an agrarian zeitgeist that held microbes as something to eradicate wholesale, rhizobial inoculants were mass-produced and widely sold to industrial soybean farmers. The success of this bio-product owed to the visibility of the root nodules formed by rhizobia. For farmers, these nodules are tangible evidence that the rhizobial inoculant had taken hold and was working. Also critical was the creation of an *in vitro* (sterile) system to produce rhizobial commodities; this was an inexpensive and contaminate-free way to produce the bio-products in large quantities. The system was the envy of early through mid-twentieth century mycorrhizal researchers who sought to "bring mycorrhiza into [industrial] agriculture," as one researcher put it. Architects of the modified *in vitro* system used to produce AM fungi told me about their desire to create "pragmatic" solutions to the environmental ills of Green-Revolution-style agriculture. In Chapter 3, I argue that AM inoculants, as created within *in vitro* systems of production, do not bring drastic changes to industrial agriculture advertised by inoculant companies; they instead provide a way to sustain an agricultural system that many see as inherently unsustainable.

Chapter 4 looks at commercial AM inoculants in the light of recent mycorrhizal research. I describe a division in communities of practice within the mycorrhizal sciences. On the one hand are the reductive and singular experimental systems that comprised mycorrhizal science for much of the twentieth century. On the other hand are research designs and experimental systems that do not look at the symbiosis in terms of one plant and one fungus, but rather as complex *communities* of plants and varied fungi and bacteria. Although in some ways the singular and the community approaches to mycorrhizal research complement one another, they can also produce contrasting results (if not contrasting positions held by mycorrhizal researchers on what constitutes the symbiosis). I discuss how new research that looks at communities of mycorrhizal fungi works to undermine claims of efficacy made by boosters of commercial inoculants. A tension arises in that many of those whose research contradicts (or greatly limits) claims as to how and when inoculants will improve plant production are funded by public institutions and rely on a strong mycorrhizal industry as proof that their research subject furthers (potentially) socially and environmentally "impactful" technologies. I show how mycorrhizal researchers at a publicly-funded institution in Dijon turn to public mycorrhizal demonstrations in order to popularize the symbiosis and its ecological importance. These researchers make use of the public demonstrations to showcase an industry—through a specific set of arable spaces—in which they claim that commercial AM inoculants have a bright and profitable future. I call these spaces arable infrastructures; they include the most heavily worked-over agrarian soils (tilled, doused with chemical products), but more so manufactured green spaces such as sports arenas and urban greenways. AM inoculants have the potential to make these resource-intensive and heavily managed arable spaces even "greener."

Methods and Fieldsites

This dissertation is an attempt to trace networks of knowledge practices, and follow them across important nodes—be they fish, fungi, people, farms, laboratories, technologies, social movements, or other occurrences.[15] In doing so, I draw from ethnographic research conducted between 2014-2018 with mycorrhizal researchers, agricultural industrialists, and farmers who follow disparate practices with different aims but share an interest in managing soil microbes, principally mycorrhizal fungi. Since the science of plant-microbe interactions and the mycorrhizal industry have become distributed throughout the world, I followed key figures in truffle farming, biological agriculture, and mycorrhizal science to laboratories, farms, forests, and conferences in Quebec, Italy, Mexico, France, and the United States. The majority of these locations served as ancillary locations to which I would travel for a week or a month. To unearth regional particularities in agrarian and scientific practice, I conducted the majority of my fieldwork in and around Corvallis, Oregon, and Dijon, France. Corvallis has been a global center of truffle science since the mid-twentieth century, while for nearly a half century Dijon has housed researchers who seek to bring the array of "ecosystem services" provided by AM fungi to agrarian soils (Gianinazzi et al. 2010). I spent roughly eighteen cumulative months in each region. Although some of my informants work with ectomycorrhiza (truffles) and AM fungi (this includes a handful of individuals at INRA Dijon and at the Forest Mycology team in Corvallis),

---

[15] This is to follow an actor-network approach (Callon 1984). For a more recent example, see Lien (2015).

it was more common to speak with and observe researchers, industrialists, or farmers who engage with one or the other.

Most of my truffle research was conducted with truffle farmers. In Oregon, I visited the orchards of 10 truffle growers and interviewed fifteen more across North America. In France and Italy, I visited an additional few dozen truffle orchards (mostly one-day visits with truffle orchard technicians and friends of orchard owners). In France, spent two months at the INRA station in Nancy, where a handful of leading truffle scientists generously provided time and even the opportunity to collaborate on an article about *Tuber melanosporum*. I interviewed and toured truffle orchards with various figures involved in the political world of French truffle production, including local truffle grower associations in Burgundy and the Midi-Pyrenees regions, as well as officials with France's National Truffle Federation (FFT). I also met with a handful of truffle technicians scattered across the South and east of France and visited four truffle-tree nurseries. Finally, I visited truffle markets in Dijon (new markets) and Richerenches (old and storied).

In Oregon, I conducted participant-observation research with researchers and students at Oregon State University and at Forest Service laboratories in Corvallis. I attended meetings of the North American Truffling Society (NATS) and met at the homes of various senior members of the group. Given the nature of truffle researchers in Corvallis, I spent even more time with these individuals in bars and in forests across Western Oregon. I spoke with a total of 17 researchers who hold or held either full-time positions that involve(d) truffle research in Corvallis, or contracts of various lengths (typically to conduct truffle surveys when research was undertaken for the Northwest Forest Plan). Many of these individuals are now retired or have moved on to other forms of employment. I also met with many of these same French and American researchers at a conference on edible mycorrhizal fungi in Mexico (IWEMM8), and at mycology conferences in the United States (annual meetings of the Mycological Society of America).

I met with many figures variously connected with Oregon's truffle industries. I observed 9 human-dog truffle hunting teams, 5 of which were employed to some extent as truffle-dog trainers, or otherwise had truffle-dog services for hire (typically afternoon excursions in the woods). I foraged with, or interviewed over coffee or a beer, 18 commercial foragers (current and retired). I met and spoke on the phone with a handful of individuals who either had run, or currently run, truffle tree nurseries (from Oregon to Virginia). Finally, I conducted formal and informal interviews with three individuals at the Bureau of Land Management.

Most of my research on AM fungi and soil drugs was conducted with mycorrhizologists and employees of biological agriculture companies. Across France and North America, this consisted of participant-observation research at 19 public laboratories and companies that work with mycorrhizal fungi. I spent three months in the summer of 2014 and a month in 2017 in Dijon, France, where I worked at the INRA agroecology laboratory, as well as with various small companies that produce biofertility inoculants and diagnostics of soil biology. I visited two more inoculant companies around Toulouse, France.

Between Quebec, California, and Oregon, I visited and spoke with employees at 15 inoculant companies. In Western Oregon, I visited four companies that offer diagnostics of soil biology and various inoculant products. I visited a dozen farms across Oregon in which growers either use biofertility inoculants or actively manage the microbial life in their soil via other means.

I complimented my ethnographic research with archival work on truffle farming and mycorrhizal science. Where possible, I combed through archives at inoculant companies, research laboratories, and even a truffle museum in the South of France (the Ecomusée de la Truffe, in Sorges). I read through many scientific reports on mycorrhizal fungi and documents at mycorrhizal labs and companies (promotional material, grey and white papers). To the extent possible, I stayed updated on important findings in agronomy and soil science writ large; I also followed the even more expansive popular literature that covers (and contributes to) the turn to beneficial microbes for farming, gardening, and the health of humans and environments.

Conducting research with both truffle crops and soil drugs, seemingly contrasting commodity forms, brings into view not just how value(s) are injected into a natural phenomenon, but how "mycorrhiza" has taken form; that is, how and where mycorrhizal practitioners have constructed a frame around the ever-changing and indeterminate relationships between plants and microbes. This is what Karen Barad (2007) would call the particular "cuts" that humans make into the broader material-semiotic fabric that makes up the world, so as to study and make sense of its complexity. Mycorrhiza has taken meaning amidst an era defined by socio-environmental ills, many of which can be traced to the post-war period. The symbiosis now picks up value as biotechnological tools turn it into a series of products (soil drugs, truffle trees, farmed truffles) that can be produced ever more consistently and at increasing quantities. These practices risk flattening other agrarian practices that feature mycorrhizal fungi (methods to nurture AM fungi already in the soil; slower and less resource-intensive ways of truffle farming) as they move to larger more industrial farms — Lyson's (2008) "agriculture of the middle," which he regards as having unique potential to uphold civic values while bringing a needed source of livelihood to agrarian communities. Mycorrhiza is thus Janus-faced: it is part of a techno-progressivist narrative (Haraway 1997) *and* a symbol of resistance to the industrial destruction (Tsing 2015). As all mycorrhizal practitioners stressed to me, *we know so little about* *the symbiosis*. As such, mycorrhiza's multiplicity surely has just begun. In attending to emergent mycorrhizal practices, this dissertation is an attempt to capture just a snapshot of its material forms and symbolic, cultural meanings.

CHAPTER 1: Hunting for Oregon White Truffles: Developing a Feeling for the Fungi

The Scientific Truffle

Trufflephilic mycologist Rosanne Healy was a postdoctoral researcher at Harvard University from 2013 to 2015. Although I audited her Biology of Fungi seminar and spent time with her at the Farlow Library and Herbarium with a team of mycologists headed by Donald Pfister, it was only when I accompanied her on a mushroom foray held by the Boston Mycological Club that I realized her passion for truffles, those fungal fruiting bodies that remain belowground. On this outing I also learned how esoteric this passion can be, even among mushroomers, itself an esoteric community.

It was a Saturday morning in early fall when I drove with Rosanne and a few other Harvard mycologists to a public forest roughly an hour east of Cambridge. The foray that morning consisted of twenty-five to thirty people. After the foray leader explained that we would all go off in the woods for ninety minutes and then meet back at the picnic tables to categorize and showcase our fungal finds, everyone took off in different directions in the woods. I had never hunted for truffles before. Curious to do so, I stuck by Rosanne. While the others delved deep into the woods, she and I slowly circled around a swath of dense woods perhaps the size of half a football field. Rosanne was looking for subtle environmental cues that would indicate where she would be most likely to find truffles. Drawing on her experiential knowledge of finding truffles in analogous environments, she explained factors that included past weather events, tree species (truffles live symbiotically with plants), and soil conditions, all of which might indicate where she should put rake to ground. Once she had narrowed in on a spot, she unsheathed a small hand rake and proceeded to clear away ground-cover before scratching into the first inch of soil. “You don’t have to go deep,” she told me. When she didn’t find anything, she replaced the soil, moved over a few feet, and tried again. She continued in this manner for the entire ninety minutes. As the mushroomers started to come back to the picnic tables, passing us en route, one of the senior mushroomers who was friendly with Rosanne stopped to tease her. She had not found anything (aside from a few mushrooms, which she gave to me). Understanding Rosanne’s hard luck, he said, “I guess we need Jim Trappe.” He went on to ask rhetorically, “Would we have found more in Oregon?”

Others, on their walk back to the picnic tables, paused with curiosity, looking at Rosanne, still on her knees, feeling around in the soil, seemingly oblivious to the onlookers. It was clear that they were not familiar with the practice of truffling, but on the topic of fleshy mushroom, they were eager to reach the picnic tables and identify (and debate about) the species they had found. I asked Rosanne if she had expected to find many truffles. “You just don’t know,” she replied, before admitting that she had thought that she would find at least a few specimens. She expressed no disappointment, and instead spoke plainly about the need to return to the same location in the future to look further. This was my first realization of how slow and hard-won is the hunt for truffles.

The reason the senior mushroomer had mentioned Jim Trappe and Oregon to Rosanne was because Rosanne had collaborated with Jim Trappe. Jim was someone I also knew, albeit only over the phone, and was eager to hear more about. His figure was nearly mythical in the truffling world, as was his headquarters of Corvallis, Oregon. Rosanne, however, had also made a name for herself finding and describing truffles in the Midwest of North America. “So are there more truffles to be found in Oregon?” I asked. “Truffles are everywhere,” she insisted, “you just have to look.” Rosanne was not convinced that Oregon—or the Pacific Northwest—contains the majority of the continent's diversity of truffles (defined loosely as belowground, sequestrate fungal fruiting bodies).[16] She cited the fact that more truffle species, and truffle ecologies, have been described in the Pacific Northwest compared to other regions in North America, and that this is due to a strong culture of truffle hunting in Oregon, which roots in the hard work and "charisma" of Jim Trappe.

In 2017, I met with Pat Rawlinson, a retired biology teacher, in her house in a residential neighborhood on the outskirts of Corvallis, a small university town in the middle of the Willamette Valley. I had come to learn more about a community of people who largely describe themselves as having been "bitten by the truffle bug." A vector for this disease, as I learned, has long been the charisma and generous teachings of James Trappe (or simply Jim, as he is known by truffle lovers worldwide). Jim spreads the truffle bug through his seductive portrayal (at conference presentations, informal talks and formerly as a teacher) of an esoteric science and an overlooked group of fungi which lay just under one's feet. Rawlinson, for example, struck truffle-science gold in her own front yard. She showed me the spot under a Douglas fir tree where she and others from the North American Truffling Society (NATS) found a truffle that was new to science. She is also co-author on a peer-reviewed paper that reset the known geographical boundaries of two species of truffles (Bonito et al. 2010). As a biology teacher Rawlinson told me that she had "a special interest in botany." This led to her to take a mushroom identification course where she first heard about truffling. She joined NATS in 1980 where she received all of her training with truffles. She is one of many "amateur" trufflers who received an informal education over long days, even weekend trips, foraging for truffles with expert trufflers

---

[16] 350 species of truffles from the Pacific Northwest have been described (Trappe et al. 2009). Such figures are not readily available for other regions in North America.

such as Jim. Learning to truffle is akin to the process that Jean Lave and Etienne Wenger (1991) describe as "indirect" learning. When "teaching" novices, Jim favors a hands-on approach to showing how to dig gingerly in the soil with the rake so as to not damage the truffle and pointing out tree species that are more likely to associate with truffles in a given season. But learning how to truffle, or what Barbara McClintock famously described as gaining a "feeling for the fungus," does not come directly from such instruction (see Keller 1983). It comes rather from many hours, over many seasons, of noticing and learning the small details of truffles and their growth. This means developing an awareness—a deeper and often tacit understanding—of the broader environment from which truffles cannot be separated.

As I spoke with other NATS members, and specifically those without training in biology who have been with the group since its founding in 1975, they similarly described the allure of finding a truffle species that is new to science. This is the incentive to forage for truffles that I call the hunt for the scientific truffle. NATS members with whom I spoke credit Jim—who officially serves as "scientific advisor" for NATS—for making this hunt possible by generously taking on what we might call "truffle apprentices." Speaking with a group of old-time members at a NATS event in 2017 on what draws them to truffling, they, like Rawlinson, described discovering a truffle new to science as "the holy grail." But this holy grail involves more than the unearthing of previously undescribed species. It is Jim who writes the paper in which the new species or genus will be officially described. And it is Jim who gives due credit to the NATS member who found the specimen by naming it after them in the Latinate binomial.[17]

---

[17] And the reason for this naming is explicit in the research paper. For example: "'Dinoffii' named in honor of Travis Dinoff, member of the North American Truffling Society (NATS) and collector of the holotype." (Nouhra and Castellano 1995; 182).

Unlike Gary Allen Fine's ethnography (1998) on mushroomers in North America, I do not analyze NATS as a "nature organization." I share Fine's interest in how organizations help build identities, but I have not seen a collective interest among NATS members in escaping "civilization" for a leisurely activity in "nature"; nor have I seen a drive to forage on lands untrammeled by humans. Where I have found a collective identity is in members' desire to contribute to a science that has been overlooked. That said, NATS is a community that could have formed around another natural phenomenon (or taxa), given that the subject be sufficiently eccentric and overlooked (within scientific or lay circles) to form a distinct collective identity; indeed, similar groups have formed around ferns (Sacks 2002) and bryophytes (Kellman 2003), among many other organisms. NATS members tend to find camaraderie in an overlapping of offbeat interests, or interest in the offbeat. Their social cohesion, and cultural capital (Bourdieu 1984), however, lies less in a context-independent or static group of objects and more in the shared process of learning how to truffle. Frank Evans, another founding member of NATS, describes his love for truffles as such: "scientific curiosity, gastronomic delight, and an eccentric delight in the esoteric."[18] As Annemarie Mol (2002) describes how a singular body becomes multiple as it passes through the wings of a hospital and is "enacted" by different medical practitioners, Evans's quote shows a multiplicity in truffle hunting.[19] In addition to the *scientific truffle* there is also the *culinary truffle*. This latter truffle has come to dominate in Western Oregon.

---

[18] For more on how mushrooming "can be an eccentric compulsion," see Fine (1998; 19).

[19] While I follow Mol's argument that objects are "enacted" and become significant to different people based on specific practices, I stop short of philosophizing about any ontological system to which the scientific and culinary truffle may point. For how specific practices and regimes of value play among the multiplicity of an above ground mycorrhizal mushroom, matsutake, see Faier (2018).

The Culinary Truffle

In 2018, I met a man-dog team in a Douglas fir forest an hour outside of Portland, Oregon. This team had no connection with NATS; they were commercial foragers, looking for Oregon truffles with culinary value. The dog's stamina and precision in hunting down one ripe truffle after another for hours on end was utterly impressive; so too was the human's ability to remain in communication with the dog while continuously reading the landscape for where mature truffles were likely to be most abundant—an ability that clearly resulted from a passion for truffle biology and ecology not surpassed by any professional mycologist with whom I had yet met.

However, his delight in being in the woods with his dog was tempered by my presence. He clearly saw my research as a platform on which to voice his opinion that Oregon's truffle industry is on a self-destructive path. He told me that the skill and time required to hunt truffles that are of top quality—while using practices that are sustainable to truffle habitats—is not valued in the new "showy" culture of Oregon truffles. He commented on the rapidly growing truffle festivals and truffle exporters that have pressured foragers to pull up immature truffles, and how this problem has been worsened by media such as a television reality show that sensationalizes reclusive and drug-addicted foragers, many of whom lack a passion for the truffle hunt, or a sense of care for forest ecologies.[20] "Anyone can come out here with a rake and go crazy… they'll find truffles," he said before making his point that television shows and news articles that suggest truffle hunting is easy, coupled with indiscriminate buyers, are ruining the craft, and the trade.

---

[20] The television show called "Unearthed" aired on the Discovery Channel in 2015. A manager at the Bureau of Land Management told me that following the reality show there was a rapid increase in reports of what he called "irresponsible" foraging. See: https://www.oregonlive.com/movies/2015/04/oregon_truffle_foragers_star_i.html

Another commercial forager with whom I spoke similarly lamented the flood of unripe and mis-identified truffles, and the increase in destroyed truffle habitats. He too commented on a stereotyped image of "meth heads" who "desperately rake" entire swaths of the forest floor. He admitted that the group exists, to varying degrees; he agrees that such economically-desperate and inexperienced foragers are harming the industry. But he also explained that attention devoted to this group draws attention away from another sort of inexperienced forager. He characterized a group of people who are willing (eager, even) to pay triple-digit admissions to high-end truffle festivals and "truffle experiences"—pricey afternoons guided by truffle dog trainers with pure-bred truffle dogs, or weekend getaways at Bed & Breakfasts that advertise truffle-hunting grounds. Both groups, he insisted—the economically marginalized and endowed—can be equally unskilled, both pose a danger to Oregon's forests and the reputation of Oregon's culinary truffles.

I heard distaste for the decidedly upscale direction in which Oregon's truffle industry is moving from multiple foragers. They often single out the Oregon Truffle Festival (OTF) as a vehicle for this cultural shift in Oregon's truffle industry. Out of the fifteen commercial foragers with whom I spoke, most who voiced such critiques remain grateful for the public relations work tirelessly performed by OTF organizers and other industry boosters. The OTF has been instrumental in educating chefs and consumers how to cook with Oregon truffles, and in raising an awareness that helps prevent mis-identified and unripe truffles. The OTF has taken great strides in bettering the reputation and raising the economic value for Oregon truffles, which everyone I spoke with in the industry agrees are vastly under-valued.

The more time I spent with old-hand foragers the more I understood that they did not oppose the mission of what I will call Oregon's new truffle culture. They agreed with the need for better education on the production and consumption of Oregon truffles. They disagree with *how* to accomplish this mission. Countering a key message that comes out of the OTF, one forager told me, "You can abuse the forest with a dog *or* a rake." Despite the fact that he practices and advocated truffle harvesting with a dog, he told me that low quality truffles are just as likely to come from those who bring a rake or a dog into the woods. Discussions over a forager's methods miss the point, he explained. The factor that now floods the market with low-quality truffles, he stressed, is the tendency for nascent foragers to want their truffles but not want to put in the work of learning how to hunt. They think that they can avoid the long cold days in which "you don't find much." This forager who has been hunting truffles for over two decades does not think that the newcomers appreciate, or even want to appreciate, the long and occasionally fruitless hours that he see as part and parcel of truffling. They have no care for the craft, no desire to build *a feeling for the fungus.*

Oregon's New Truffle Culture

By all accounts, the past five years have seen a rapid uptick in untrained foragers and dogs roaming Oregon's forests. In this chapter, I will consider if this reflects a weakening of the truffle bug—a reduction in the feeling for the fungus—that risks tarnishing Oregon's well-respected truffle culture. Or if this new attention to Oregon Truffles owes to a new strain of the truffle bug, one able to infect larger crowds and just as likely to incite a strong feeling for the fungus, albeit on different terms.

Oregon's truffle culture has changed drastically in the past few decades. A string of funding cuts and personnel reductions has hit Corvallis' truffle research community. At the same time, participation in NATS forays has declined. The recent wave of interest for Oregon's culinary truffles seems designed to fill this void in Oregon's truffle culture: declining are those attracted by an esoteric practice of foraging for hidden organisms via indeterminate environmental cues in mundane and forbidding places; meanwhile, a much larger group that is attracted less by the *process* of truffling than by a few ostentatious objects and landscapes have come to constitute and be representative of Oregon's new truffle culture.

As I foraged and spoke with those new to truffling in Oregon, I found them driven less by an uncontrollable infection for the hunt of the organisms—which often involves long days in unromantic locations—than by a desire to display their involvement with truffles to networks of gourmands, both local and global. I was reminded of Thorstein Veblen's (1899) analysis of America's Gilded Age, specifically his description of "conspicuous leisure," basking in a past-time that requires pre-accumulated capital and doing so in a way that will be visible to the right cultural groups.[21] Such displays and aesthetics of wealth (pertaining to people, truffles or landscapes), I found, have been a source of discomfort and alienation for those in Oregon's older truffle community.

But at least since the famed nineteenth century food essayist Jean Anthelme Brillat-Savarin, truffles have been a food and symbol for the affluent. Feelings of alienation was of the least concern for those venerable truffle researchers and commercial foragers with whom I spoke. What they feared was a new culture of trufflers who seek to short-circuit the learning process—the enskilling—that is necessary to develop not just a feeling for the fungus, but a feeling for the mycorrhizal connections and broader ecologies of which truffles are a part. This was not a wholesale condemnation of the new truffling culture but a worry that it does not come

---

[21] Veblen's analysis was about socio-economic classes. Although it contains an upper-class aesthetic of luxury, Oregon's new truffle culture crosses socio-economic lines.

with the same affective attachments to forested ecologies, or a respect for the indeterminacies of truffle biology— all which makes truffling laborious yet rewarding.

This chapter traces transitions in Oregon's truffling community. It begins with a tradition (an infection) for truffle hunting that has roots in the nineteenth century but did not spread in earnest until the late twentieth-century. The truffle bug infected a close-knit group and instilled a feeling for the fungus that lasted a lifetime and was fueled less by the truffles themselves than the development of the skill of truffling—a skill understood as a necessarily situated and embodied practice shared across a community of practitioners (Grasseni 2009; Jones 2011). Oregon's new truffling community is driven less by an enskillment that occurs within eccentric social circles and requires many years spent in often uninvitingly cold, wet woods. Instead, this new truffling community is infected by a truffle bug that concerns the circulation of goods rather than practices, a bug that has reached them via haute cuisine marketing with a polished, affluent aesthetic. These goods include high-end restaurants, designer dogs, glamorous truffle festivals, and of course the truffles themselves.

This shift in truffle cultures begs the question: can the expanding, ostentatious interest in truffling (as industry boosters anticipate and promise) co-exist with healthy truffle ecologies in Oregon? To what extent can Oregon's ecologies of truffle production be intensified or expanded? What would these ecologies look like? Who or what will be left out—or priced out—if lands are increasingly privatized, standardized and valued explicitly for Oregon truffles, or if truffling permits are issued only for those with specifically trained dogs? More to the point, will the new strain of the truffle bug be able to instill a feeling for the fungus potent enough to spread subjectivities (inoculations of the mind) that will foster stewardship of Oregon's truffling ecologies? Some in Oregon's older truffling culture fear that the new truffle bug is less about spreading *the feeling for the fungus* (a passionate interest in the skill of truffling that includes a respect for truffling lands), and is instead a mere *selling of the feeling*.

Chapter Roadmap

This chapter unfolds by first describing the truffle science edifice that attracted so many trufflers to Oregon, at the heart of which was Jim Trappe. Jim found himself perfectly positioned to provide motivation and guidance to a community of dozens of amateur and professional trufflers, who then devoted lifetimes to the pursuit of the scientific truffle. This initial part of the chapter builds my argument for the slow and embodied process of developing a feeling for the fungus (not unlike what Isabelle Stengers [2018] calls "slow science"). I show how individuals persistently carry out the mundane work of truffling in the same locations for decades and are driven by a "delight in the esoteric," which has bound them into a close-knit community of practitioners devoted to the skill of truffling and building awareness of truffle ecologies and truffle science.

The chapter then moves on to investigate how the truffle bug has spread as Oregon truffling culture has become more conspicuous. I discuss how an appreciation for truffles shifts with the new culture that centers less on developing a feeling for the fungus, which builds through years of seeking out and discovering truffles. The new culture takes no issue with avoiding the trails and errors of hunting for truffles where they are not likely to be found (which is precisely where the joy of the previous culture is located). Many of Oregon's nascent trufflers find gratification in being a part of a larger culture of gourmands; they are not interested in foraging where truffles may or may not be found, and instead go straight to those forests primed (to the extent possible) for ease and consistency of production. This is proving to be an incredibly successful strategy for attracting new truffle aficionados. I end the chapter by discussing the pressure put on truffle harvests, even by those who hold an appropriate feeling for the fungus. We might say that Oregon's culinary truffles are in the beginning stages of what Sidney Mintz has called an "extensification" of tastes— only instead of a case in which the lower-classes of Britain develop their own tastes and culinary customers for sweetened foods and drinks, extensification among Oregon truffles includes a broadening of truffle tastes that includes those who dine at Michelin-starred restaurants to those who are willing to pay an extra ten dollars for a truffled dish at a Portland food-truck. It remains to be seen how this broadening of tastes will impact the ecologies of production for Oregon's culinary truffles. Will irresponsible and untrained truffling increase, putting more acreage of Douglas fir forest at risk? Will Oregon truffle extensification create more awareness for non-timber forest products in general, and better use of Oregon's forests by Oregon's communities? Or will it lead to the closing off of prime truffle lands by emergent truffle entrepreneurs?

PART I: Hunting the Scientific Truffle

Jim Trappe, retired mycologist and NATS' scientific advisor, is central to the story of the hunt for the scientific truffle in Oregon. In the final quarter of the twentieth century, he helped make the small town of Corvallis *the* global center for truffle science, while laying a foundation for a vibrant regional culture of truffling which included those with all degrees and manners of training (in and out of science). Jim did not build this culture on his own, it relied on the material, epistemic and cultural infrastructure of a genealogy of trufflers in the American West.

To do this, Jim relied equally on his talent for finding and identifying truffles as he did his talent for storytelling. To NATS members, it mattered that these stories were of famed truffle hunters who carried out the practice as both a vocation and an avocation.

The earliest figure was Harvey Willson Harkness. Anecdotes that I heard recited at forays (by Jim and by others) and genealogies written up in mycological articles have enshrined Harkness as the indisputable "godfather" of truffle taxonomy in North America. Harkness began collecting around the San Francisco Bay Area, eventually expanding his region to include most of California. Within the international community of mycologists, he gave the American West a reputation as a place robust with truffles.

Growing up impoverished in mid-nineteenth century western Massachusetts, he still managed to earn a M.D. degree at Berkshire Medical College in 1847. Harkness moved to California during the Gold Rush and grew successful enough with his medical practice to become Leland Stanford's physician (Werner 2006). The fact most boastfully cited about Harkness is that he rose high enough in social circles so as to have the honor of handing off the golden spike at the 1869 celebration at Promontory Point, Utah, which marked the completion of the first transcontinental railroad. For truffle science, the definitive period in Harkness's lifetime came with his retirement from medicine at age 48 (*ibid.*). This is when Harkness focused his energies full-time on his "hobby" of collecting fungi. He began by collecting and documenting above-ground mushrooms. In these early days of his hobby, he sent most specimens to Europe for professional mycologists, such as Mordecai Cubitt Cooke in London, to verify and name. However, as he amassed his own fungal herbarium, and became more skilled at collecting and identifying fungi, he increasingly wrote his own papers and monographs in which he described fungi new to science. Toward the end of the century, he had been fully infected with the truffle bug, and developed a feeling for foraging the scientific truffle that was unprecedented in North America. He published his monograph on truffles, widely considered to be his masterpiece, two years before his death in 1901. This compendium on truffles, *California Hypogeous Fungi*, describes 108 species of truffles, 55 of which were new to science (Harkness 1899). Writing to European mycologists, Harkness explained that he did not need to go deep into the wilds to find truffles. His favored truffle spots were in rather populated locations such as Mount Tamalpais and Mill Valley in Marin County (*ibid.*).

Working with Jim, NATS's founding members decided to take up Harkness's strategy of repeatedly returning to well-defined locations, in the search of new truffle species and new habitats of known species. NATS set up five carefully defined locations (of less than a square mile each) where they would regularly survey for truffles. In letters to mycologists, Harkness writes of the joy he received from truffling in well-known lands.[22] As with NATS members, the joy of the hunt did not come from escapes to swaths of wilderness in which one felt apart from civilization. Quite the opposite: NATS members took pleasure in finding the overlooked as it lay (in fungal form) beneath soil regularly trammeled by humans. The skill of finding truffles was less about epic walks in deep woods than in spending long hours in known spaces and hunting in the same locations amidst changing environmental conditions (seasons, weather patterns, changes in vegetation).

In his ethnography on foragers of aboveground mushrooms in the United States, Gary Allen Fine seeks to "understand how humans tame nature into their models" (1998; 19). Fine introduces the analytic "naturework" to describe how mushroomers' practices reflect three

---

[22] Biographical information on Harkness is limited and scattered. Aside from newspaper articles, herbaria notes, and personal letters, biographies have been written by mycologists and progeny, such as this blog entry from Martha Karen Buchanan accessed on July 24, 2019: https://camcca.wordpress.com/dr-harvey-w-harkness-man-of-science/

distinct visions of nature: protectionism, organicism, humanism. Within a tradition of truffling in North America, which we can trace back to Harkness, I suggest that the skill of the hunt arises less from an impulse to escape into the wilderness so as to enjoy what Thoreau has called the "tonic" of nature, and more from upending—or disregarding—expectations about where one can expect to find and learn from the unknown in nature. Learning how to truffle, and the enjoyment reaped from this experience, I argue, is a process of learning how to perceive the world differently. Jakob von Uexkull (1957) used the term *umwelt* to describe the unique ways in which organisms perceive and act in the world. He used the now famous example of the phenomenology of a tick (with its ability to detect the heat and chemicals given off by a sweaty mammalian body, and to wait for extended periods of time between feedings). Trufflers likewise learn that truffles cannot make their own food as plants do, and instead connect with the roots of specific tree species to gain carbon by forming an ectomycorrhizal symbiosis. Trufflers learn about food webs in which small mammals such as vols and flying squirrels rely on truffles for their diet, and in which predatory birds, such as the endangered spotted owl, rely on such small mammals for their own sustenance (Maser et al. 2008). Whereas Fine centers his analysis on how mushroomers construct meaning from "nature," and then use nature as a "staging area" for culturally meaningful stories, I found that NATS members generated collective purpose by learning and being a part of an esoteric science, a small club in need of hard-working members.

Harkness inspired a host of mycologists in the Bay Area, including W. A. Setchell. Setchell was the doctoral advisor of Helen Gillkey, who is most certainly the professional figure most discussed by Jim and the NATS community.[23] Gilkey is a tangible link between early-twentieth-century truffling in Oregon and the truffling of Jim Trappe's era. This connection is

---

[23] Upon graduating with a PhD in 1915 from U.C. Berkeley, Gilkey would become the first woman to earn a doctoral degree in botany from the University of California system.

one many Oregon trufflers are aware of and value. I heard variations on the following anecdote over a dozen times during fieldwork, from Jim and others in Oregon's truffling community. The story takes place in 1965, when Trappe was relocated from the USDA Forest Service Station in Portland, Oregon, to the station in Corvallis, which was located on the OSU campus. This also happened to be the year that Gilkey decided to move out of her office at OSU, where she had continued to work since her retirement in 1951 (Trappe 1975). One day, as Jim eagerly walked across campus from the Forest Service's research center to the OSU Botany Department to introduce himself to Gilkey, he had no idea that she was at that moment packing up the truffle herbaria. She had put this herberia together, along with colleagues (notably Sanford Zeller), over the last several decades and it was precious to her. Having found no eager trufflers to adopt the herbaria, Gilkey had reluctantly decided to send it to the New York Botanical Gardens, a reputable location for mycology (otherwise the specimens were sure to get moldy, or be forgotten and eventually thrown out). This was the context into which Jim walked. He entered Gilkey's office that day already having been bitten by the truffle bug, and already familiar and admiring of Gilkey's work. While Trappe introduced himself, he noticed that Gilkey was in the process of packing her herbarium, along with the books and other items in her office. Tappe's enthusiasm for truffles must have been palpable, for midway in their conversation, Trappe noticed that Gilkey had begun to unpack everything that she had just packed. She told Trappe that she would give him everything, and that he was to carry on her effort of cataloging truffles in Western Oregon.

As with Harkness, Gilkey did not collect and document truffles in earnest until after her retirement as a botanist (as well as illustrator and herbarium curator) in 1951. Even if she took advantage of the scientific materials available through her position at OSU (microscopes, scientific literature), working with truffles was strictly an avocation. This was precisely the case with Sanford Zeller, a plant pathologist at OSU during the early to mid-twentieth century. Although Zeller passed away in 1948, many years before Gilkey would carry out her most important work with truffles, the two were known as Western Oregon's truffle hunting duo (Gilkey 1949). While it appears that they rarely hunted together, both spent nearly all their spare time hunting truffles.[24] Today, Gilkey and Harkness are better known for their work with truffles than for their professional undertakings. This point has not been lost on NATS's amateur members.

The most prized item that Trappe received from Gilkey may have been what he now calls "the heritage fork." This is a truffle fork whose tines have worn down or snapped off multiple times and had to be welded back on; the handle has been replaced at least once. This truffle fork, at the direction of various humans, has unearthed more truffles than perhaps any other truffling instrument. As I heard from NATS members, the heritage fork, in Jim's hands at NATS forays, has sparked many anecdotes about one's dedication to truffling and how truffling legacies can be passed down to subsequent generations. The fact that truffle science history in North America focuses primarily on the leisure time of a handful of collectors made NATS members I spoke with feel as if they were in on a secret, as if they were part of a secret club (although "education" is an explicit purpose of NATS, still truffling, at least in the twentieth century, attracted a small segment of society). Jim Trappe harnessed this sentiment to sell truffle hunting to seasoned mushroom hunters whom he suspected would take joy in going deeper into the fungal

---

[24] Zeller's niece, who was interviewed in 2016 by Corvallis mycologist Michael Castellano, explained that her uncle never went anywhere without his truffle fork. He would take it on all afternoon excursions and weekend family camping trips. Those who knew Gilkey reported similar behavior. Despite the possibility that Gilkey and Zeller rarely collected together, they collaborated in other ways. Gilkey only worked with one sort of truffle (ascomycetes), while Zeller worked with another (basidiomycetes). All of the ascomycetes that either found went to Gilkey, while all of the basidiomycetes went to Zeller. This deal is reflected in the scientific literature: Gilkey's publications are on ascomycetes while Zeller's are on basidiomycetes.

underground. For those who were attracted to an already esoteric activity—mushroom hunting—delving deeper into the soil and into esotericism by hunting truffles had, as I found while digging in the woods with Rosanne Healy back in Massachusetts, a definite appeal.

Mycologists have written about the dearth of labor undertaken with, and interest in, Kingdom Fungi, especially in comparison with other plant and animal taxa (Pringle et al. 2011; Hawksworth and Lücking 2017). In the 1970s, Jim was well aware that truffles were even less represented in the halls of science. He made great efforts to popularize truffling in Oregon. His knowledge of truffles was matched by his generosity with this knowledge: his willingness to spend long hours teaching all manner of students from professional mycologists to those without any training or experience with fungi to speak of.

After being transferred to the USDA Forest Service's research station in Corvallis, Jim quickly became principal investigator of the Forest Mycology team. He brought more money in grants to the Department of Forest Ecosystems at Oregon State University than anyone else.[25] By the mid 1970s, and into the twenty-first century, Corvallis was known internationally as a hotspot for forest mycorrhiza. Among truffle taxonomists, it was hardly disputed as *the* global center of researchers. As Dorothy Bergstrom (1976) wrote in a white paper for the Forest Service of the U.S. Department of Agriculture, "At present, probably more people are involved in mycorrhizae research in Corvallis than anywhere in the world."

With a team of PhD students, employees hired for specific assays (on two- or three-year contracts), and a continual stream of visiting scholars, Jim oversaw a team that numbered up to twenty people. These individuals were dedicated to the time-consuming, and often fruitless, work of truffling in Western Oregon. One researcher active in the 1990s described Western

---

[25] Jim frequently won departmental and university accolades for his ability to bring in funding, as told to me by a few of his students.

Oregon as a region whose truffle ecologies are known better than anywhere else. Nonetheless, compiling such knowledge into a coherent picture that portrays the diversity and ecology of truffles in the region would require more than a team of a dozen or so dedicated mycologists. Such a project would require the help of amateurs without training in the biological sciences.

The North American Truffling Society (NATS)

The founding of the North American Truffling Society (NATS) in 1978 had a few catalysts. Founding NATS members told me varying stories about early formative events. Most revolve around the cultural anthropologist and ethnobotanist Tony Walters. In the 1970s, Walters offered a course in mushroom identification at Linn Benton Community College. For one session, he invited Jim to come speak about truffles, which in turn made the course more popular. Soon, a group of mushroomers were hooked and dedicated to learning more.

Also in the mid-seventies, Jim gave what a few participants described as a "brown-bag lunch" talk at a public space on the OSU campus. Jim covered truffle biology and ecology with attention to the role of truffles in forest ecosystems. He spoke of vols and flying squirrels, whose diets (depending on the season) can comprise up to eighty percent truffle. Unlike "birders" or other social groups that form around more popular and charismatic organisms, this crowd was drawn to the esoteric, the unknown, and as Jim would help them realize, the underground. Jim described an underground filled with fungal fruit, an overlooked booty to those eager for a new hunt. Jim's invitation (if not provocation) was clear: if you choose to take up the hunt, you are bound to find species (and habitats of known species) that are new to science.

Following Jim's talk at OSU, attendees passed around a piece of paper to collect contact information. When they reconvened to discuss the formation of NATS, they agreed that the truffle-hunting society would not merely promote "awareness" of truffles, or how to find species and habitats already known in the scientific literature. NATS would *contribute* to truffle science— and this would only be possible if Jim Trappe were willing to serve as dedicated scientific advisor. Without an ongoing commitment from Jim and other mycorrhizal researchers in Corvallis, such as Nancy Weber and Michael Castellano, the eager amateur trufflers knew that their efforts would not have legitimacy or legibility in professional scientific circles. Jim accepted the position, and has been the lead scientific advisor for NATS ever since.

With Jim Trappe's help, NATS was founded with a carefully conceived plan for how members would hunt for truffles in a way that would be of value for truffle science. They created a research design that included five swaths of land of roughly a square mile each. These locations were not chosen as bucolic getaways but as practical locations to which NATS members could regularly return over the subsequent decades. To make "scientific collections," NATS members did not need to go deep into the woods, they merely needed spaces protected from future development and clear cutting. Frequently visited parks near Corvallis, such as Marys Peak State Park, would work just fine. These designated spaces aside, it turned out that most of their rare scientific finds (including species new to science) came from spaces regularly trammeled: cemeteries, parks in or on the outskirts of Corvallis, and even green spaces within Corvallis itself. As Trappe recounted to me, such places often have incredible truffle diversity. Still, professional collectors are more likely to pass them over for ecologies that are more rare (if not in another hemisphere). Regardless of where the hunting takes place, NATS members would need more aim than randomly digging beneath trees. They needed to be trained.

Enskillment

Teaching truffling requires an education on broader assemblages of flora and fauna. More than learning the connections that often lay hidden in forested ecosystems, the challenge of learning how to truffle well comes from learning how to re-attune one's senses and expectations towards familiar landscapes. Learning to read landscapes so as to do more than blindly rake the ground requires an iterative process of finding truffles, mentally processing for environmental indicators (tree species; soil moisture; weather; season), and then learning to recall these environmental cues on future occasions when foraging in a similar environment. This is why face-to-face training with an experienced truffler is needed, training that is not a one-off workshop, but extended across time and repeated in numerous sessions.

Truffling is a matter of reading the landscape, across time and biological Kingdoms, to estimate where truffles may be found before putting rake to ground. Seasonality is the first obvious clue. Mycelia, or fungal threads from which truffles grow, follow seasonal patterns of growth and dieback (along with roots, dead mycelium is a critical food source for soil critters). Spring, when mycorrhized root tips and mycelium are growing with newly formed roots, is the time to look for many genera of truffles; other truffles proliferate in the fall, before roots and mycorrhiza die off. Even within the specific truffle seasons, one has to look out for conditions that are almost certain to prevent truffle growth. This could be due to dry spells or unseasonal deep freezes. Then come more site-specific factors, such as a slope in the land, particular aspects of the slope, and the growth phase of nearby trees. When hunting for the scientific truffle (i.e. hunting for a wide diversity of truffles), a truffler will anticipate which taxa may be around; this judgement then indicates which tree species to dig around, and the depth at which to dig. All of these skills will not only lead to more fruitful hunts, but also prevent a naive or over-zealous truffler from simply digging up multiple square-foot patches of soil in search of any truffles that may be below. For this reason, a committee formed by NATS wrote a "Truffler's Code of Ethics." This code states that NATS members are to be taught how to truffle in an environmentally responsible manner. As one member told me, this involves more than "replacing your divots," those small clumps of dirt reminiscent of what is unearthed with the swing of a golf club. NATS members must be taught where soil environments are fragile, such as on certain slopes and near tree lines. All members must know general properties of forest soils to understand why they should or should not truffle in certain ways. This was the foundation for creating a truffle-centered form of land stewardship. And if the Code is followed, as Jim likes to say, a truffler does far less damage than a squirrel who digs around for underground food.

Jim instilled in his PhD students, as well as visiting scholars, the necessity to demonstrate epistemic generosity toward those with an interest in truffling but without training in mycology. Michael Castellano, who is now in charge of the lab that Jim once led, told me how Jim created a culture in which professionals valued the time they spent teaching amateurs to truffle. All that was required was passion: that the individual in question had been "bitten by the truffle bug." Skills could be acquired, in time. Jim and his colleagues would spend long days and entire weekend forays (e.g. the yearly retreat to the Andrews Experimental Forest) collecting truffles while training inexperienced NATS members.[26]

The professional-amateur relationship was mutualistic. That broader communities developed a connection with and appreciation for truffles was critical for the future health of truffle science, and of truffle ecologies. Jim had what one forager described as "an army of

---

[26] Jim was also good about balancing this work with fun. Even among professionals, he insisted on creating a culture of working hard, and then continuing the day's work over Oregon's famed IPA, at one of the town's many bars.

folks… with forks in the ground." Jim told me that he never could have imagined how much success and popularity NATS would achieve—especially among amateur hunters.

Scientific Contributions

When I asked a member of Jim Trappe's team what made NATS members valuable to truffle science, he described their willingness to hunt in places that had been written off by professionals. These were often mundane spaces such as backyards and city parks. "They look in those very average places where we don't bother," this researcher told me. Often, these are places where (or conditions under which) professionals had unsuccessfully looked in the past, and have since written off. Or they are places where researchers did not have access, a good example being Pat Rawlinson's front yard, where, in 1980, she found a truffle new to science, *Gymnomyces rawlinsonii.*[27] Other amateur NATS members such as Henry Pavalek and Wells Bushnell are credited in scientific publications for their work in describing and cataloging numerous species of truffle fungi.[28] In some cases Jim will create a Latinate binomial, an official scientific name for the fungus, in the honor of NATS member who has found the "holotype" (the specimen that will be used to describe the new species and will be preserved and kept in a herbarium for future reference). In one instance Frank Evans found what turned out to be a highly valued holotype. The specimen he found came from "late successional forests in the range of the northern spotted owl," and molecular and morphological analysis would show that it

---

[27] The name (which may become *rawlinsonie*) and description of the species has yet to be described in a peer-reviewed paper. As a few NATS members told me about science: "the wheels turn slowly." It was originally a *Martellia sp.*until molecular analysis showed it to be within *Gymnomyces*.

[28] Either the species in named in honor of the NATS member who collected the specimen, for example *Thaxterogaster pavelekii* Trappe, Castellano & P. Rawlinson; or the NATS member is listed as a co-author for the description of the species, for example: *Tuber pacificum* Trappe, Castellano & Bushnell.

belongs to its own genus. Jim named this genus after Evans: *Fevansia aurantiaca* (Trappe and Castellano 2000; 153).[29]

Even if finding a species new to science was "the holy grail," this was not the explicit aim of NATS. Such an achievement was more of a crapshoot than a research plan for a society centered on contributing to science. As NATS members have written, the group "is a specialized scientific and educational, nonprofit organization (Rawlinson et al. 1995; 171)." Founding NATS members were intent on learning and generating new knowledge about the habitats and geographical tendencies of specific truffle species. To this end, these founding members set up five collecting sites. Forays would regularly be held at these sites for decades. To standardize the information that would be collected during these forays, data cards were designed. Frank Evans took a leading role in creating these cards. When we spoke at his home in a neighborhood just south of Portland, he showed me a small portion (a few hundred) of the data cards that he has procrastinated in giving to the NATS archive. He designed two versions of these data cards which include entries such as collector name, date and time of collection, elevation, understory and overstory plant species, slope, sun exposure, etc. These cards were to be filled out with every specimen collected. They then took these plans to Jim, for refinement. NATS members were encouraged to do this work, with the confidence that it would (one day) be useful to science.

Looking at these cards across the years allowed NATS members to distinguish patterns in fruiting, indicating favorable conditions for specific species. As Evans explained, analyzing the data from these cards enabled NATS members to see that a truffle common to Douglas fir

---

[29] Why the species was named as such was made clear in the publication:"The generic name, Fevansia, is in honor of the collector of the holotype, Frank Evans of the North American Truffling Society" (Trappe and Castellano 2000; 156). The publication goes on to recognize NATS' work in collecting specimens for the Northwest Forest Plan, the publication states: "This series is a project of the North American Truffling Society (NATS) (*ibid.* 177)." Aurantiaca is Latin for "pale orange," the color of the outside of the truffle.

forests, *Tuber gibbosum* (described by Harkness), tended to fruit in two different times of the year: late fall and early spring. This caused the group to question if there might be two species at play. With those at the Forest Mycology team they conducted close morphological investigations and indeed found subtle differences between the truffles that fruit at these different times. Subsequent molecular work separated *T. gibbosum* (which fruits from January to June) from the new species *T. oregonense* (which fruits from October to March) (Bonito et al. 2010). This is just one example of NATS members with no prior training in science being co-authors in prestigious mycological journals.

NATS members were also proud of having done work for the Northwest Forest Plan which supported surveys of organisms in old-growth to settle disputes over the ecological impacts of certain logging practices (Hays 2007; Holthausen et al. 1994). As NATS members wrote in a 1995 paper in a mycological journal: "NATS collections provided crucial data on fungi for use by the Forest Ecosystem Management Assessment Team appointed by President Clinton in 1993 to resolve issues related to timber management in the Pacific Northwest (Rawlinson et al. 1995; 172). Aside from species collected for the Northwest Forest plan by 1995 NATS members boasted that "[s]o far about 100 probable new taxa have been discovered" (*ibid.* 172).

Trappe was incredibly successful in building a culture in which NATS members were, to the extent possible, on par with researchers with PhDs. NATS members were not barred from the lab at the Forest Service, and were instead encouraged to come on a weekly basis to perform microscopy work to identify and catalog truffles. In the articles he published Jim regularly credited NATS members such as Welles Bushnell for their work organizing and preparing specimens for herbarium accession. NATS members continued to perform such laboratory work during my fieldwork period.

Moving to the Center of Peripheral Participation

NATS exemplifies one of many models through which professionals work with amateurs. It is a model in which amateurs can move closer to the enskilled center of what Lave and Wenger (1991) call the periphery of learning. A necessary component of this model was to set up a system in which Jim would not have to personally train all NATS members. As a few NATS members learned more skills, they became the ones to teach subsequent NATS members (or those who, for one reason or another, had stayed on the periphery).

Researchers who collect from areas in the Global South have employed the term "parataxonomist" to refer to those who provide on-the-ground expertise. One example of parataxonomy is when researchers from industrial centers of the Global North travel to forests of the Global South and rely on the expertise and labor of those who dwell in tropical forests to find the organisms in question (Basset et al. 2004). This is a type of place-based learning which requires many years in the environment in question, a type of knowledge researchers who live and work in another hemisphere usually will not have had time to obtain. These researchers thus rely on those who have place-based knowledge and insight. Insight into where and when organisms grow, depending on complex environmental factors; insight, too, into restrictions that arise from local politics, land tenure, and so on. The term parataxonomist makes clear the hierarchy of knowledge and perceived contributions to the labor of science making (see Lowe

2006; Soto Laveaga 2009).[30] Historically, there have been few attempts to move parataxonomists into the enskilled center.

More recently, there have been increased attempts to train scientific laborers (be they in the Global South or North), but these efforts remain greatly restricted and policed by what science studies scholar Thomas Gieryn (1999) calls "boundary work," which upholds divisions between those with and without scientific credentials. Jim does not do away with such boundaries. With NATS, there remains an element of "para" (or peripherality) to epistemically prestigious centers. If nothing else, this power structure exists because NATS's amateur members are reliant on Jim to write up the papers and undertake the final identification of specimens (which may have to be matched against type specimens in distant herbaria). Indeed, I heard complaints about specimens sitting on Jim's desk for years before the trufflemaster could get around to doing the work.

Despite minor critiques, by setting up a culture in which professionals spend ample time training amateurs, co-author with them, name fungi in their honor, and invite them into their labs, Jim made great strides in opening up a USDA Forest Service research station that does not typically let in amateur biologists. Jim has significantly shifted (and softened) the boundary between who is rewarded (and how) for the labor and skill involved in truffle science.

Giving credit to amateur researchers is not unprecedented. I argue that what makes the culture of Jim's Forest Mycology team at OSU/the USDA stand apart is their willingness to spend long hours training NATS members. This is what separates NATS from the now proliferating phenomenon of "citizen science," a term popularized by initiatives such as

---

[30] Experimental researchers have their own divisions of labor. The most blatant, and accepted, being the division between lab "technician" and "researcher." As with parataxonomists, technicians may be mentioned in the acknowledgements sections. But this does not acknowledge that the skill of these technicians—the ability to perform fastidious, meticulous tasks—often surpasses that of lead researchers.

Zooniverse. NATS succeeded because of a core of a dozen or so amateurs who spent decades learning from Jim, from other core NATS members, and from the landscape. NATS members boasted to me of the prestige of publishing in journals and having their names transformed into official latinate binomials. But they were not after fame; I got the sense that they were happy with the club's level of popularity and foray turnout (30 to 40 people at a crowded foray). The wanted the accolades but they were best served in small doses from an equally esoteric audience. Jim had the foresight (or was just lucky enough) to see that investing so much time in these amateurs would build a thriving community of trufflers who would contribute to science and build an appreciation for the diversity and ecology of the underground fungi.

As I spoke with NATS members, they consistently told me how thrilled they had been to be brought into this close-knit community. Seeing them at larger mushroom conventions like the annual convention in Portland, Oregon, their small display table with its smaller crowd felt like a secret.

Summary of the Scientific Truffle

The potential to contribute to science-making (as co-authors or simply by performing valued work) is what Rawlinson described to me with such emphasis. This was the drive to go forward with the hard and slow work of developing a feeling for the truffle. NATS members were fully satisfied to have unearthed specimens, or to have collected data, from suburban tree lawns. The "wilds" of Oregon reside in such mundane spaces just as they do in the state's old-growth forests. This is not to say that many NATS members were against the protection of old-growth forested ecologies, nor that they did not relish excursions to such environments (forays at Andrews Experimental Forest continue today). But this observation does show a departure from the perception that fungal foragers are out for pristine walks in the woods (Fine 1998). For NATS members, it was almost a greater thrill to find the underground bits of wild—those organisms unknown to science—in their very own backyard, or any other regularly trotted soilscape, so as to show just how overlooked the fungi are.

But I do not want to oversell the impact of this work within the halls of science. Viewed from the life sciences writ large, NATS has provided minimal contributions to an esoteric science. Mycology remains a minor branch of the biological sciences, while truffle science is a sub-branch of mycology. Hierarchies and concentrations of study within the life sciences have not changed that much since Gilkey's day. This was part of the draw for NATS members: they were foot soldiers for an underrepresented science, one long neglected and, in some respects, never fully begun. They took pride in having learned the craft, and in passing this know-how on to anyone else who would be so dedicated (or so infected by the truffle bug). Jim still strives to ensure that such generosity in teaching remains central to the practice of truffling in Oregon.

Beyond the contribution to science, and beyond publication in prestigious mycological journals, as founding NATS member Frank Evans said, "pleasure" was an important motivating factor. While Evans and other members reveled in the esoteric delight of truffle science, they also partook in the culinary delight of truffles. When I spoke with Evans, his biggest point of pride seemed to come not from having a genus named after him, but in a National Geographic article that features a meatless turkey that he and Karan (his spouse) would make every year for a NATS pot-luck. This is another part of Oregon's truffling history: the culinary truffle. This story begins in the 1960s, and yet again, Jim is front and center.

PART II: The Culinary Truffle

In 1968, Jim Trappe took a sabbatical from his position at the Forest Service to visit the fungal collections of one of Europe's most famed truffle taxonomists, Carlos Vittadini. But his trip was not only archival. He also went truffling, in the managed and unmanaged lands of Northern Italy, where the famed White Truffle from Piedmont grows. He became familiar with the appearance and aroma of this Italian truffle, which is the most expensive fungus in the world. Back in Oregon, he realized that one of Oregon's local truffles was not unlike the one that drove Italians and Italian economies wild. He explained this similarity during the two talks that founding NATS members cited as catalysts to North America's first truffling society: Jim's 1975 talk given at OSU, and his presentation for Tony Walters's mushroom identification seminar at Linn Benton Community College. The truffle in question was *Tuber gibbosum.* Like *Tuber magnatum* in Italy, it has an off-white exterior, light tawny interior, and an aroma that mixes garlic and soil, with additional notes that can only be called *truffle*. Trappe had never heard of Oregonians hunting for this truffle, which fruits in abundance in young Douglas fir forests with closed canopies and relatively clear of ground cover. Douglas fir, known in Oregon's logging community as the "cash tree," proliferates across the wet low-lying hills of Oregon's Coastal Mountain Range. Following clear cuts, loggers tend to plant the cash tree exclusively. The species is also popular as a Christmas tree. Around the turn of the century, the State of Oregon gave incentives to farmers who went into Christmas tree production. The specialty industry still thrives in Oregon, but the hype of Christmas tree production has also led to the not uncommon sight of abandoned Christmas tree farms. In short, there are plenty of ideal environments for *T. gibbosum* in Western Oregon. To help boost the truffle as an important product for the regional economy (not to mention a boost for truffle science in Oregon), Jim came up with a colloquial name for the species: The Oregon White Truffle.[31]

When Tony Walters approached Jim about talking at his mushroom identification seminar, he initially hoped that Jim would have something to say about the use of truffles by indigenous communities (past and present) in the region. Jim had little to say on the topic, which, as mycologists frequently lament, speaks volumes about early Europeans in North America and their disinterest in and ignorance of fungi (who failed to appreciate what indiginous knowledge there might have been).[32] Bringing Oregon Whites to the attention of Tony Walters was fortuitous, as Walters would be the one to secure *T. gibbosum*'s place as the best known truffle in Oregon. Aside from taking the lead in founding NATS, Walters also teamed up with his spouse, Mary, to organize a symposium devoted to the human use of mushrooms in the Pacific Northwest. It would be held in the fall of 1977 at Linn Benton Community College, and they would name it "Mushroom and Man." The symposium was an inclusive and well-balanced representation of Oregon's diverse mushroom cultures. Presentations covered psychedelic mushrooms (as given by alternative medicine guru Andrew Weil, and a criminal defense attorney who spoke about "The Legalities of Mushroom Experimentation"), folk uses ("medico-religious" aspects), forest ecology, industrial mushroom cultivation, and "Future Perspectives of

---

[31] As mentioned above, thanks, in part, to research done by NATS, there are two species that fall under the name "Oregon White," *T. gibbosum* and *T. oregonense.* In this chapter I use "Oregon White" to capture both edible species. There is also a black truffle (*Leucangium Carthusianum*, or the Oregon Black Truffle) of culinary value that is native to Oregon, and fairly common.

[32] Even if Jim had little information to provide Walters in the 1970s, his awareness and respect for indigenous communities in the area is great. When deciding on a name for a new genus of truffles that are brown and choice edibles, he and his colleagues noted that the truffle has only been found to grow in an area that matches where the Kalapuya people have historically lived. He called the community leader and asked how they would feel about having the genus named in their honor. They told Jim that they would be pleased, and thus the genus is now called *Kalapuya brunnea*. Jim and coauthors include this explanation in the scientific paper that describes the genus and species (Trappe et al. 2010).

Commercial Mushroom Production in the U.S.." The symposium brought together commercial pickers, industrial growers, chefs, spiritual leaders, taxonomists and ecologists.

The most memorable aspect of the symposium for many was the presence of the nationally renowned chef James Beard. As an Oregon native, Beard was eager to come and experiment with the Oregon White Truffle for himself. He gave a presentation on the culinary bounty that Oregon has to offer, and ended the symposium with a cooking demo that featured the little-known Oregon truffles. Although Walters had invited Beard as a promotional effort for Oregon truffles he could not have foreseen the lasting impression Beard would make on Oregon's future truffle industry. Beard offered a remark that would reverberate within culinary circles from Oregon to New York, and which I heard quoted countless times during fieldwork: Beard declared the Oregon White to be every bit as good as its Italian counterpart, which can go for thousands of dollars an ounce. There is some debate about when Beard actually uttered the words,[33] but regardless, the message was loud and clear.

NATS data cards are filled with finds of Oregon White truffles. The species is common and the majority of NATS members still covet the fungus. Needless to say, when foraging they will not overlook a stand of trees in which the truffle is likely to lay. Most certainly, culinary truffles were and remain a draw for NATS members. Frank and Karan Evans still make their famous truffle-stuffed non-meat turkey. In the 1990s, NATS published an official truffle cookbook (North American Truffling Society 1984).

---

[33] Reviewing the proceedings for the Mushroom and Man conference, I could not find the quote. Insiders in Oregon's truffle industry have told me that he said it during the cooking demo. Famed New York City-based mushroomer Gary Lincoff wrote that Beard later repeated the sentiment in NYC (1983 McIlvainea 6 [1):] 13-15).

The formation of NATS and the Mushroom and Man symposium were well timed with the growth of the more general "wild" products industry in the Pacific Northwest. Many Oregonians with temporary or part-time employment took to the woods seasonally for the commercial mushroom trade. These were individuals seeking gifts for family members, barter with friends, seasonal money on the side, or a principal means of livelihood. Networks of Oregonian mushroom pickers formed, which included distributors and brokers, with figures such as "Lady Mushroom" on top. As Anna Tsing (2015) has written about, by this time a community of migrant pickers largely from Southeast Asia was also present in Oregon's forests. During the final quarter of the twentieth century, and into the twenty-first, all of these figures could, at times, make good money selling and brokering mushrooms that include chanterelles, morels, boletes and matsutakes (Jones 2012; McClain and Jone 1997). It was not long before the commercial foragers who hunted in the higher parts of the Cascadian Mountains caught wind of Oregon's culinary truffles.

In 1983, Walters sought to incorporate truffles into the thriving Oregon mushroom industry. He began an early company devoted to the sale of Oregon White truffles, giving it the rather awkward name "Ethnobotanical Research & Development Enterprises, Inc.[34] Compared with others in the industry, Walters's company did not last long. Likely this failure resulted from his method for dealing with the exceedingly short shelf life of the truffle. Oregon Whites are some of the most perishable of truffles; depending on when they're picked, they may turn fowl in just a few days. Walters's decided to sell the truffles frozen, a transformative process that stifles the ephemeral organoleptic qualities of truffles.

---

[34] Walters's company worked in conjunction with the producer and packager Happy Gnome Forest Foods. In promotional material he boasts of his training as a cultural anthropologist (having earned a Master's Degree), with certificates in pharmacology and ethnobotany.

Other truffle distributors followed multiple practices at once. Low-grade truffles, or those about to go bad, were mixed into sauces or preserved in alcohol, while higher quality truffles were sent via overnight delivery to locations beyond the Pacific Northwest. I spoke with the manager and co-owner of a Washington, D.C.-based truffle distribution company who described bouncing between the airport and D.C. restaurants where he sold directly to renowned chefs. He expressed doubt that such a business model could be so easily pulled of today. The 1990s, when he was in business, were a time of lax airport security by today's standards. Truffles were easily shipped overnight from Portland, Oregon to Washington, D.C. at last-minute notice. In D.C., the truffles would go for a far higher price than anywhere in Oregon. Even with the then (relatively) open airports, this business plan was not without difficulties. This truffle broker told me how stressful it was when he learned that a shipment with dozens of pounds of truffles had been rerouted from D.C. to Texas!

This truffle broker, who soon got out of the business to work as a researcher, did not end up being representative of current commercial trufflers with whom I spoke. Thirteen of the fifteen commercial truffler hunters with whom I spoke held primary jobs in the construction or service industries. They worked full- or part-time as cooks and bartenders, in retail or as construction subcontractors. Most were able to work fewer hours at their day jobs during peak truffle season; still, they explained, squeezing in both tasks was often exhausting. For these individuals, truffling is one piece of a greater effort that is cobbling together a life in Western Oregon.[35] Others, who may have sold some truffles but did not rely on this money as a source of

---

[35] One forager told me about an increase in professionalization among foragers. He felt that there was an ever-growing number of people trying to make truffle foraging their full-time pursuit, in some cases even finding and selling directly to buyers outside of Oregon. Part of this professionalization is a reduced willingness to yield to the unpredictability of truffle harvests (certain days bring in many pounds and certain seasons bring windfall profits; other seasons bring mediocre earnings). This means more pressure to harvest immature or overmature truffles. I did not notice this trend toward professionalization; but my sample size was small, and it is also likely that this category of foragers were unwilling to speak with an anthropologist.

livelihood, were retired policemen or schoolteachers. While all the foragers with whom I spoke would likely identify with the desire to be free of inflexible working hours and the constant oversight of a boss, and relished each day spent in the woods—as Anna Tsing (2015) describes with migrant Matsutake pickers in Oregon—all but two were resigned to the fact that they could not support themselves (or their families) by picking and selling truffles. The one commercial forager with whom I spoke who refused to take another job was unable to make rent and instead lived at friends' houses for extended periods of time. When I visited him at one friend's house, both he and the friend made unsolicited remarks about the strain on their relationship caused by their housing situation; they were actively seeking alternatives.

Skill of the Commercial Hunt

While hunting truffles for species diversity requires one skillset, hunting for Oregon Whites requires another, no less sophisticated, set of skills. Although commercial foragers read landscapes for well-known indicators of just one or two species, they still rely on nuanced skills that are difficult to master. They need to know which landscapes will have the desired species, and at which stage of the species' growth it will be salable in commercial markets. The basis of their feeling for the truffle shifts from knowing truffle taxonomy and diversity to knowing how to unearth Oregon Whites at specific points of maturity, and how to collect quickly, efficiently, and in quantities that will be worth the forager's time. Some buyers demand large quantities of truffles that are slightly less ripe, compared to others who have no specifications of quantity but need a truffle that can be served immediately.[36]

---

[36] There is a debate among researchers and foragers on what degree of immaturity one can pick a truffle and still have it mature as though it had remained in the ground. Truffle brokers, of course, would like to extend as long as possible this period in which a truffle can properly mature after being picked. Most truffle experts doubt that pushing this temporal boundary can extend a truffle's "shelf life" beyond four or five days.

Getting a feeling for the culinary truffle concerns less where they *can* grow, and instead where they can be found in very precise stages of growth. These truffles must also be found with a certain degree of ease, which will, in financial terms, make the hunt worth the forager's time. The need for efficiency is greater for those with higher living expenses or for those who do not have another means of livelihood. Despite the matter of income, the commercial foragers with whom I spoke often measured success and satisfaction through quantity of truffles found as a function of time spent and effort exerted. Good commercial foragers have an uncanny ability to know when (down to the day) it will be worth their time to head to the forest. They depend on knowledge of previous weather patterns and the progress of the season, as well as past experience foraging in regional forests, to know where to drive and begin the hunt. Once there, they employ more fine-grained knowledge to know where to direct dog or rake. Finally, when truffles are found by either a dog's paw or a rake's tine, the forager engages in a rapid-fire split-second series of decisions on which truffles to collect and which to leave in the ground.

Truffle Dogs

In the 1980s, there was a rapid growth in NATS membership and commercial foragers with rakes; truffle dogs, on the other hand, were slow to come onto the scene.[37] One reason may be the lack of dog trainers and dog-training programs (which would come later). The early dog-led foragers with whom I spoke, in a sense, got lucky with their dog companions. I do not mean to downplay the hard work of training the dog-human team—the mutual training that always goes on between two species that interact so closely. But the successful dog-led foragers with whom I spoke all had dogs with ideal, even-keeled temperaments for the job. As one dog trainer told me,

---

[37] As of 2018, NATS forays remain almost exclusively raking affairs. They rarely include more than one dog (dogs are not allowed in certain forests).

it is a fallacy to say that some dogs have better noses than others, and that this attribute is what makes a good truffle dog. All dogs, this trainer insisted, have a sense of smell that is far more sensitive and nuanced than would ever be needed to find those incredibly smelly fungi, no matter how deeply buried they may be. The rare trait is to have the right comportment and discipline for the job. This means an ability to focus on one smell to the exclusion of others, and to do so for extended periods of time. Getting the dog in the mood to hunt, and making sure that she knows when it is time to work, is a large part of the challenge.

All of the truffle dogs I met in Oregon are also thoroughly loved pets who sleep and eat in the same house as their owner(s). In contrast, most of the truffle dogs I met in France are considered "work" dogs, not "pets"; they are not allowed in the house, and are considered something different from the (typically smaller) pet dogs who sleep in the house and go out and about with the owners.[38]

There are other truffle dog cases too, of course. I met a Portland, Oregon resident who has been truffling with dogs for over two decades and does not even own his own dog. He borrows, or "dog sits" others' dogs, only instead of "sitting" or walking around the block, he takes them truffling. The forager explained the benefits of this set-up: he has no commitment with dogs who, for one reason or another, are not suited to truffling.[39] It also precludes the need to indicate to the dog when it is time to hunt truffles; that is, when the dog should focus his or her sense of smell on truffles and truffles alone (not other animals, for instance). "Whenever we are together, the dog knows exactly what to do," the dog-sitter told me. For a truffle dog who is as

---

[38] Many truffle hunters whom I met in France have a rotating crew of at least three truffle dogs, which are perceived and valued differently from any dog that is allowed in the house and considered a part of the family. In Oregon, I did not meet a truffle dog that was not treated the same as any beloved pet; this makes it difficult to be honest about the abilities of a subpar truffle dog, much less rehome them. See below for more on keeping truffle dogs who rarely truffle or do not perform the job well.

[39] I found that the inability of owners to admit that their dogs are not cut out for the job is a common issue among Oregon trufflers (or prospective trufflers).

part of a family as any homo sapien member, knowing when to focus exclusively on truffles can be a significant challenge, for human and canine alike.

With an enthusiastic and focused truffle dog, a forager has less need to develop the skills of reading an environment for cues on truffle growth. She can simply go into a Douglas fir stand with trees between twenty and eighty years old, and of an elevation of no greater than two thousand feet, and let the dog go. I have spent many days hunting with dogs in which we covered a lot of ground; when I trufffled without dogs, we tended to go to a few select locations where we passed most of our time. On or off leash, the dog owner is busy keeping up with the dog, and responding to subtle desires and messages from the dog, knowing when to reinforce certain actions of the dog (or not), and determining which truffles to leave in or pull out of the ground. Foraging with a dog is not a sure way to harvest ripe truffles, because even under- and over-ripe truffles emit a strong aroma easily detectable by dogs. It is only a well-trained dog that goes exclusively for ripe truffles (occasionally dogs are "naturals" at the task). I have seen many dogs go for truffles that are under-ripe and should remain in the ground—this is where reinforcement becomes important (dogs receive treats only for ripe truffles). Then there is the skill of the human to know which truffles to keep; in some cases this includes resisting the temptation to collect unripe truffles, despite knowing they would likely go unnoticed in a batch of ripe truffles.[40] All of this is to say that when foraging with dogs, much of the needed skill shifts from reading the landscape to reading the dog.

From Unearthing to Earth-forming

---

[40] Some in the industry claim that they can detect (smell) even a single unripe truffle in a batch. This may be true for some purveyors; regardless, it certainly is not a common ability.

A significant debate within Oregon's truffling community concerns the question of overharvesting. In many discussions, this complex question is simplified to a dichotomy that shows rakes as leading to overharvesting while dogs do not. Jack Czarnecki is a strong proponent of the use of rakes to sustainably harvest truffles. Czarnecki is a member of a mushroom and truffle hunting family that has been in the Willamette Valley for a few generations. As he makes clear in public statements, he does not need to venture far off into the woods to hunt truffles. He has arrangements with landowners in which he can hunt on their prime truffle grounds. Such arrangements allow trufflers to cut out the process of finding the right area in which to hunt. They already have full reign over what one forager described to me as "primo" land, and they do not have to worry about other foragers beating them to the chase. They simply return to the private land often during truffle season, and they do so year after year. This method has enabled Czarnecki, manager and co-owner of the famed Joel Palmer House Restaurant in rural Oregon (founded by his father), to sustain a restaurant that boasts "cooking [that] revolves around wild mushrooms and truffles which we [the Czarnecki family] gather ourselves and with friends."[41] Czarnecki is perhaps the most vocal proponent of raking as an excellent way to truffle commercially. Countering claims that link raking to overharvesting, he explains how his family has been raking the same swath of Douglas fir forest for over half a century—and the quantity of truffles has not decreased. Czarnecki insists that raking can be every bit as effective and ethical as dog-led foraging. And he is not alone. He is part of a greater voice that insists that debates of overharvesting should concern proper training and ethics, and less so the tools used to forage. Situations in which one has exclusive rights to a truffle hunting ground—especially in cases where this land is used exclusively for truffling (and from harvesting the trees decades down the

---

[41] As quoted from the Joel Palmer House Restaurant webpage, accessed on August 5, 2019: http://www.joelpalmerhouse.com/about

road)—move the debate from how to prevent harm to fungal communities to how to aid truffle production.

With knowledge that certain Douglas fir stands produce more Oregon Whites than others (notably abandoned Christmas tree farms planted on sloped pasture land), it was not a big leap for landowners to try to sculpt forests that would allow sustained or increased growth of Oregon Whites. One such landowner was NATS member Paul Bishop. Bishop passed away before I began fieldwork, but his land—not to mention a generosity that had no qualms with thirty or forty truffle-hungry people repeatedly raking his land—remains the stuff of NATS legend. All who visited Bishop's land agreed that it was unusually rich with truffles; they did not agree, however, on whether or not Bishop intentionally formed the landscape to be so prolific with truffles, especially Oregon Whites. A NATS flyer from the 1990s that promotes a foray on Paul Bishop's land reads "the most researched and productive land in Oregon." The flyer even hints at "methods" used by Bishop and another NATS member, Dan Wheeler, that may have brought this truffle wonderland into being. Wheeler was more vocal about ways to boost the production of Oregon Whites. He discussed the topic in opinion pieces in popular journals such as *Mushroom: The Journal of Wild*, as well as in online forums.[42]

Most in the NATS community at the time were aware of Bishop's experiments with ways to boost the growth of truffles on his land. Unfortunately, no one could provide specifics on what Bishop had done. A few would mention "re-seeding" the land with spore slurries (a liquid infused with ground up truffles—which are essentially sacs of spores). But how did he apply this slurry to trees and soil? What else was he up to? Researchers from the Forest Mycology team

---

[42] There is plenty of anecdotal evidence supported by NATS data cards and foray reports that clearly indicates the impressive quantities of truffles found on Bishop's land. But I could find little evidence of the techniques carried out by Bishop (or perhaps Wheeler).

had the most to say, but they always preceded the discussion with comments such as, "we have no idea if there were any effects at all." They refused to vouch for the efficacy of Bishop's measures due to a lack of "sound research design." Bishop did not set up any "controls," or areas that were replicas of the treated spaces but received no treatment. "Without leaving any of it alone, how can you determine impact?" one researcher said to me. Only after qualifying their answers with such rhetorical questions would they discuss techniques. I heard about the aforementioned spore slurries that were designed to spread Oregon White truffle spores throughout the stand, with the hope that the spores would germinate and meet with rootips (then potentially grow into new truffles). How best to apply these slurries was not entirely clear or unanimous. I heard from two researchers that Bishop dug narrow trenches around the drip line of the tree, and then sprinkled in the slurry. I also heard about him clearing away plant life from the forest floor to reduce competition with the Oregon Whites and avoid diminished truffle growth; this method would also make harvesting easier.[43]

NATS members were impressed with Bishop's sense of experimentation. Bishop's actions fit well with their practices of knowledge formation and experimentation around truffles; he displayed yet another way in which one could gather a feeling for the truffle.

Bishop fit right into Oregon's truffling culture in another way. He was incredibly generous, perhaps to a flaw. In the 1990s, when NATS was at its peak, he would host forays on his land that included forty plus people. Researchers at these forays described to me their concern as they saw, over the course of the day, Bishop's land become thoroughly raked through.

---

[43] These methods are not unlike what has occurred in France for the production of another culinary truffle, Tuber melanosporum, since the early nineteenth century (Le Tacon 2017). It is unclear whether Bishop or Wheeler knew about or were inspired by such techniques, but it is likely that they had some idea of the European methods. There was a big push in Europe to spread truffle cultivation methods, beginning in the 1960s with the formation of truffle-grower associations in France and Italy.

One participant told me about turning to Bishop and saying, "Do want us to tell these people to slow down? Tell them to rake more gently?" Bishop gave an insistent "No!" and explained that the most important thing was that they enjoy themselves.

Bishop did not strive to profit from this fungally fruitful land. He instead turned it into an outlet to attract more NATS members and allow them to experiment with how to boost truffle production. Bishop's land is an early example of land being valued (economically, socially, scientifically) expressly for its bounty of truffles. This is a trend that we will see more of with bed and breakfasts set among Douglas fir forests that advertise (and have raised rates because of) the Oregon Whites that can be found on the land.

NATS was founded as an explicitly non-commercial organization and is filed under a non-profit status; it is made up of members who take the pledge to abstain from commercial activity very seriously (when other members have attempted to take NATS in a more commercial or political direction, they have been pushed to leave).[44] With the turn of the century and the rise of commercial truffle foraging NATS members retained a productive balance between community, environmental and commercial interests. Stephen Gudeman (2008) calls this a market and mutualism dialectic: while Oregon's larger truffle culture certainly had commercial aspects, NATS did not let this hamper the generosity and openness that are also deeply ingrained in the culture. NATS instead took the role of strengthening communal bonds and sustaining an ethical position regarding truffling. These values were enshrined in NATS Truffler's Code of Ethics.

---

[44] I saw this occur with the editor of *The Truffler*, NATS's official newsletter. The editor wanted to include political positions on potential changes to Oregon land-use zoning (which put truffle habitat at risk). He was told he could not do this and quit as a result. In a separate case, Charles Lefevre stepped down as President of NATS shortly after co-founding the Oregon Truffle Festival. Members felt that he had increasingly used his position to promote the commercial festival, and in other ways sought to take NATS in a more commercial direction.

Despite the importance of NATS in Oregon's truffling culture and regional truffle science, its role has diminished notably in the last few decades. The same can be said for the role of the Forest Mycology team in Corvallis, formerly led by Jim Trappe. To many insiders today, the growing popularity and commercialism of culinary truffles in Oregon has been the key factor in keeping the state's truffling community strong. This argument in itself reflects the dwindling presence of the Forest Mycology team.

Jim officially retired in 1996. But, as was the case for Gilkey, this has in many ways allowed Jim to be even more productive and involved in truffle-human communities and truffle taxonomy. Randy Molina succeeded Trappe as lab head, and under Molina's tutelage the lab continued to thrive. A big part of this was the Northwest Forest Plan, which Bill Clinton signed into law in 1994, following what historian Samuel Hays (2007) has called a "war in the woods." This was the fight between environmentalists and industrialists over logging practices, such as clear cutting, which endanger charismatic fauna such as the spotted owl. Since the spotted owl's survival relies both on the old-growth trees in which they nest (and the trees rely on mycorrhizal fungi for their health) and on rodents (who in turn rely on truffles for their survival), the Forest Mycology team received funding to carry out a series of truffle surveys. The 1990s and early 2000s were a lively period for truffle researchers in Oregon. But this funding barely lasted into the second decade of the twenty-first century.

NATS members had always been attracted to the overlooked, literally and figuratively; they were interested in a novel kind of hunt. In the 1970s, so few people had ever scratched into Oregon's soils looking for truffles that the belowground fungi made for wonderfully esoteric subjects. By the turn of the century, it was harder to make this case. Perhaps NATS members had already grabbed up all of easier finds to contribute to truffle science—the low-hanging fruit, so to speak. As NATS moved into the twenty-first century, the group made fewer scientific contributions. This might also be due to the dwindling number of NATS members who went out on forays. Even though NATS's scientific contributions have diminished, a strong scientific mandate remains: truffle science and education are still central to the group. Also central to the group are culinary truffles, though the nature of this interest is not quite in line with that of other Oregonians with a passion for truffles. For many of the latter group, this interest has become something to flaunt, a way to feel not part of an esoteric community, but part of a much larger community that follows the latest food trends, a community in which truffles have become an ostentatious display that confirms identity and membership within a global culinary-consumer community. Today, many in Oregon work hard to be sure that Oregon Truffles hold a prominent place in such a culture of conspicuous food consumption. They see it as necessary for the continuation and growth of Oregon's truffle culture.

PART III: Oregon's New Truffle Culture

The annual Oregon Truffle Festival (OTF) represents and performs (cf. MacKenzie et al. 2007) the new culture of truffling in Oregon. The festival revolves around two crowning events. First, a series of truffle-dog training seminars which culminate in the Joriad truffle dog competition. Second, many days of truffled, white-tablecloth breakfasts, lunches and dinners which culminate in the Grand Truffle Dinner. Analysis of the practices and aesthetics of these events helps show the accomplishments of Oregon's new truffling culture, and why some in Oregon's older truffle culture hold concern for this new direction.

Designer Land

The Joriad competition involves two rounds. In the first, dozens of human-canine teams meet at a public fairground for a competitive hunt of truffle-scented bait as spectators watch from the bleachers. In the second round, those who have been singled out as cream-of-the-crop head to a private Douglas fir forest just outside Eugene, Oregon (to this, spectators are not invited). Not unlike Paul Bishop's land—an abandoned Christmas tree farm that had been planted on sloped prairie land—the forest is an absolutely ideal location for Oregon Whites. It is well-known among truffle hunters that Oregon Whites are likely to thrive in such an environment, and although this is private land, it is a loosely guarded secret among trufflers that it has been foraged for quite a few years without permission from the landowner. Charles Lefevre, a co-organizer of the Oregon Truffle Festival, decided to approach the owner for permission to hunt in the truffle-rich stand (such arrangements are not uncommon between tree farmers and foragers; they typically involve the landowner getting a percentage of any profit). The owner was more than amenable to the idea, and the relationship grew into the forest being the official location for the Joriad Competition.

There just happened to a bed and breakfast on the property, so this may have sweetened the deal for the landowner. Surely, when first speaking with Lefevre, the vision of adding economic value to the bed and breakfast by making it a truffle-hunting destination (for paying guests only) came to mind. The vision has since been realized: the bed and breakfast is now solidly booked during truffle season. At the Oregon Truffle Festival, I spoke with a few couples who either already had reservations at the bed and breakfast or longed to. One couple had a trained dog; the others had dogs that still needed training (they were at the festival to accomplish this). The trufflers' bed and breakfast has become a training ground for people and dogs, as well as a way for both human and canine to reap the rewards of truffling without going to the "trouble" (as one hopeful bed and breakfast guest put it to me) of finding truffling locations on one's own, and worrying about whether or not the land is private or public, and if public, whether or not truffling is permitted (on truffling permits, see Oviatt 2017). What is "trouble" for this truffler is precisely a point of satisfaction for many other trufflers. We can view the trufflers' bed and breakfast as a commodified short-cut in the process of truffling: it cuts out some of the uncertainties of truffling, uncertainties that—as NATS members and commercial foragers explained it—develop and feed into a feeling for the truffle. Many festival attendees who have come to train their dog have full-time jobs in unrelated fields and do not have the time to survey for truffling locations, nor do they have the desire to do so. Theirs is a desire for quick satisfaction (via found truffles) that some hardier foragers deride, dubbing these short-cutters fair-weather (or fair-country) trufflers, as they are unwilling to put in the time, patience, and labor that makes the hunt so rewarding. Even if this is the case, the bed and breakfast provides an important outlet for this crowd. Without being able to pay entrance to promising truffling territory, they may very well have been discouraged from getting into truffling in the first place. Such is the rationale behind a wide range of truffling services that have risen in the past decade.

The past five years or so have seen a flourishing of truffle dog trainers and handlers who offer everything from group classes on basic scent training in city parks, to personal guided tours of bucolic secret truffle patches. The latter may even involve a cooked meal. This is popular among out-of-towers (whether they come from Portland or Tokyo) who have no interest in getting a truffle dog, but want the "experience" of going on a truffle hunt.[45] Here, the convenient and fair-weathered hunt is taken to the extreme. The trainers see to everything in advance; above

---

[45] Truffle "experiences" have become an official (and popular) "Airbnb Experience," offered from Italy to the Pacific Northwest.

all, they must visit their secret locations the day before the scheduled hunt to ensure that some truffles will be found. A dry hunt (which is part and parcel of truffling) would be unacceptable for those paying for the full truffling experience.

Designer Dogs

The burgeoning truffle dog training and foraging industry boosts the sales of truffle festival tickets. Truffle festivals have sprung up from the San Francisco Bay Area to Seattle; also on the rise are entrepreneurs who train truffle dogs and sell truffle-dog "experiences," typically afternoon outings foraging with dogs in lands known to be favorable for truffle production. The two business models feed into each other.[46] Chares Lefevre is the figurehead of the OTF and he uses this public platform to push a narrative of dogs-not-rakes.[47] Lefevre is frank about why this message makes sense. Moving beyond questions of truffle quality or forest health, he said publically at one OTF: "It's easier to sell dogs than rakes." This statement concerned how best to market truffling in Oregon. But marketing for the decidedly upscale OTF is not just about dogs, it is about a designer breed called the *Lagotto Romagnolo*, a water dog whose existence dates back to the 1400s in the Italian region of Romagna (Fogle 2000; 248). Allegedly the dogs have continued to be bred in the present-day region of Emilia-Romagna, most recently for the act of truffling. Despite the fact that everything from labradors and chihuahuas consistently win the Joriad, every bit of publicity material for the OTF includes a Lagotto Romagnolo. Lefevre himself bought two of them a few years before we first met in 2015.

---

[46] The Oregon Truffle Festival recently became a non-profit organization. Officially, the business model is now one exclusively about the promotion of truffles, so as to aid the many surrounding industries.

[47] He (or his publicist) is also an incredibly savvy with public relations: Lefevre managed to be in just about every news article on truffles during my fieldwork.

I have yet to meet a dog handler who argues that the breed as a whole produces good truffle dogs. What counts is the individual (hence a chihuahua winning the Joriad; but note that small dogs do not have the energy for a full day of hunting and trekking in the woods). The point is not that Lagottos are any worse at truffling; there is simply no evidence that the breed is necessarily better at the task than any other. In Oregon's coniferous forests, with low-lying branches and brambled undergrowth, I am not convinced that a Lagotto is the best choice. This skepticism came on a day hunting with a typically curly-haired Lagotto (the kind of hair that requires regular trimming) and a short-haired Labrador. We were in a very typical Douglas fir forest. That day we had the dogs on leashes (most foragers do not use leashes); I was holding the Lagotto's leash and the owner of the two dogs was holding the Labrador's. The poor Lagotto was trying her best to keep up with her more-experienced companion, but kept getting snagged by the wiry, bushy ground cover, from blackberry and salmonberry brambles to stinging nettles. I spent a good portion of the hunt stooped down, striving to untangle the whimpering dog. Occasionally the Lab would run back to us, and look on anxiously. The owner finally said: "I guess those Italian forests are not like our fir forests."

Such practicalities notwithstanding,[48] Lagottos have been publicized (and widely perceived) as the *right* dog for truffle hunting in Oregon. The breed carries with it a potent class symbolism (associated with luxury), and possessing a Lagotto is a sign that one is part of a new culture of truffling, one that has increasing currency across the globe (see Chapter 2). The several-thousand-dollar price tag on the dog is no deterrent to these new trufflers, something I

---

[48] There are other practical issues. The expense of the dogs (tens of thousands of dollars) is linked to their rarity in North America. With the rapid increase in demand and an increasingly short supply, there are now troubling claims of inbreeding. The dogs already receive a low score for friendliness to humans; complications following inbreeding evidently make this trait worse (see Fogle 2000). I heard plenty of such gossip among dog breeders and handlers in the Pacific Northwest.

saw in evidence at the Hilton in Eugene during the OTF. The medium-sized, curly-haired dogs were everywhere, with the near exception of the Grand Truffle Dinner, where I happened to glimpse one weaving around the besmoked chefs and white tablecloths.

Forest Hot Pots to Grand Truffle Dinners

In 1975, Santa Rosa, California became the first location in North America to hold a truffle festival. The Western Truffle Festival was conceived, sponsored and organized by Henry Trioni and Ralph Stone. Promotional material for these truffle festivals (a second was held in 1987) describe Trione and Stone as "California financial barons." Trioni was "board chairman of Wells Fargo Mortgage Co.," while Stone was "executive vice president of Great Western Savings and Loan Association." With such high-level positions, the two mean had a hand in the development of the financial and physical infrastructure of Santa Rosa—in the form of bank loans, high-end shopping malls, planned neighborhoods, vineyards, even a complex of horse-polo fields, a pet project to be sure.

Trione and Stone were bitten by a rather upper-class strain of the truffle bug while "aboard the Ile de France," a yacht in the Mediterranean on which the tycoons "were served veal in truffle sauce." Truffles would become another pet project for the men who were always looking for a conspicuous investment. With word that new technologies enabled the cultivation of Mediterranean truffles beyond the Mediterannean (see Chapter 2), they sought to bring this upper-class glamour, this conspicuous consumption of truffles, to Santa Rosa. With the right promotion, they saw great economic potential in making Sonoma County America's ground zero for culinary truffles. This pursuit, of course, led them straight to Jim Trappe. When Jim mentioned that the Oregon White also grows in California, the barons' commitment to promoting truffles in Sonoma was cemented.[49] In addition to the two truffle festivals in Santa Rosa—to which the barons flew, in their private jet, roughly a dozen NATS members from Corvallis—they funded a PhD student to work with Jim on truffle production in the Pacific Northwest.

Trione and Stone would make claims to fly in the first truffle dog to North America (from the "one true breeder" in Alba, Italy). A dog was not the only organism they would fly from Italy to California. Promotional material for the 1975 Western Truffle Festival boasts wine tastings featuring the best wines from Geyser Peak Winery, followed by five-course meals, the crowning plate being "fettucini with white truffles. The white truffles—two pounds, valued at $500—will arrive, packed in ice, on October 30." Stone and Trioni's careful noting of the price and mode of transport of the famed Italian truffles highlights why local production of culinary truffles was so important, and why the potential economic windfall of turning Sonoma into a globally recognized truffle-producing region was so great.

When I met founding NATS member Pat Rawlinson at her Corvallis residence and we looked at photo albums of NATS events, there were dozens of pictures from the Santa Rosa festivals. I spoke with a few other NATS members who attended the festivals. They all expressed their surprise at the exuberant glamor of the event. Most NATS members were familiar with eating whole truffles in the woods, out of a Dutch-oven over a campfire. Commercial foragers and NATS members alike happily recounted the delights of such crude fungal "hot pots" (as one forager put it), into which went dozens of whole truffles mixed with sundry other forest edibles. This was worlds apart from having raw truffles shaved, tableside, over four of five courses by a five-star chef. One NATS member, Frank Evans, who spoke at the later truffle festival in Santa

---

[49] They were not discouraged by the fact that not everyone agrees that the Oregon White is as tasty as the Italian White; they were confident about their ability to overcome such a perception.

Rosa (in 1987), even quipped in a letter to the organizers that he expected to be picked up from the airport in a limo. He had heard that they did this for Jim Trappe years earlier.

“Overharvesting”: a New Issue to Confront in the 21st Century

The Santa Rosa conferences occurred in a time when truffle foraging in the American West was still in its infancy. By the time the 1990s hit, the situation had changed. Researchers, foragers and federal employees tasked with managing and policing public forests had to confront a new issue: overharvesting.

With the turn of the twenty-first century, when Jim Trappe was writing up an opinion piece in North America’s leading journal for the mushrooming community, *Mushroom: The Journal of Wild Mushrooming*, he seemed to question his initial promotion of the Oregon White Truffle. His opinion piece warned of the perils (realized and potential) of over-harvesting. The article begins by exhibiting the skill of trufflers who use dogs in Italy. He then segues to the problem of unskilled raking in the Pacific Northwest. Trappe makes the easily digestible prescription that when foraging commercially: *use a dog.*[50]

I first heard about the problem of overharvesting during an early interview with NATS member Frank Evans. He gave me a few early copies of *The Truffler*, the official newsletter of NATS. He explained that the newsletter used to contain the exact coordinates of found truffles; this was helpful for scientific documentation. By the late eighties, NATS members noticed a trend in which those published locations were subsequently ravaged by “irresponsible raking.” When I asked Evans what he meant by irresponsible raking, he said “utter decimation.” He

---

[50] I have spoken personally with Jim Trappe about poorly trained dogs, and poorly trained humans with otherwise apt truffle dogs. When writing an eight-hundred-word opinion piece for a nationwide readership of foragers, Trappe deemed it best to give the most straightforward narrative that would do the most good, even if this meant neglecting or discrediting some truffling talent.

described the forest floor as entirely raked over, before saying that he would find pictures of such abused forest floor to share.

By 2015, the situation had gotten so out of hand that the Bureau of Land Management (BLM) got involved. The BLM is a federal agency that oversees the largest amount of public forested land in the U.S. (the USDA Forest Service is responsible for a smaller amount of land). BLM employees are responsible for policing BLM land against illegal commercial foragers of mushrooms and many other products. The track record of the BLM and the Forest Service's policing of public lands and the "products" therein shows that such officials are not always generous to individuals and companies that are not major economic players.[51] However, I found Jim LeComte, the BLM's Special Forest Products Coordinator, to be both passionate about truffling and sympathetic regarding fairness. He spearheaded an effort to control forest raking that led to the first dog-harvesting truffle permit in North America; in 2016, the permit became available in limited areas (Oviatt 2017). When I first met LeComte at the headquarters of the Salem District of the BLM, I did not expect to find someone so enthusiastic about truffle hunting. LeComte certainly had been bitten by the truffle bug. He discovered the passion while trying to forage with his dog—though when we spoke, he was a self-described "failed" dog-led forager who was determined to persist. LeComte also loves the taste and aroma of Oregon Whites. He told me about bringing Oregon Whites into the BLM office for his colleagues to try, and being met with indifference or repulsion (LeComte admits he is not representative of Oregon BLM employees).

After discussing his truffle passion, LeComte told me about why he pushed to create the license. He was responding to a need. He received an increasing amount of calls, he explained,

---

[51] For non-timber forest products, see (Lynch and McClain 2003; McClain and Jones 2005); for race and class-based oppression that carries over into forest management, see Braun (2002) and Kosek (2006).

from residents wanting to know if and how they could legally forage for truffles on BLM land. There were rules set up for mushrooms, but not truffles (a case brought against a truffle hunter by a BLM ranger was thrown out of court for this distinction between mushrooms and truffles). LeComte sought a way to make truffling possible on BLM land. When I asked why he only created a permit to hunt with dogs, he raised the issue of "overharvesting." For proof he showed me pictures that I had already seen from multiple sources in Oregon. They were of a swath of Douglas fir forest approximately the size of a tennis court. The duff, or cover of needles and other debris which tends to be maybe two inches thick, of the entire area was raked clean, with little piles scattered everywhere. When seeing the image, one does not need a scientific report to feel a visceral reaction over the environmental harm—this was a form of forest decimation in which the trees remained standing.[52]

LeComte caught wind of the benefits of foraging with dogs via the well-promoted Oregon Truffle Festival. By the time LeComte heard about the festival, its organizers were pushing the message that if the reputation and quality of Oregon truffles are to improve, *we must all hunt with dogs*.

Promotion of Oregon truffles: Too Much of a Good Thing?

The Santa Rosa festivals, though certainly gourmand, were not only shaved truffles and white tablecloths. They were also filled with mycological expertise from Oregon, France, and Mexico, as Stone and Trioni knew that they had a responsibility to support and build the science around

---

[52] Around the turn of the twenty-first century, Randy Molina, Trappe's successor as head of the Forest Mycology team, assigned David Pilz to research potential ecological impacts of truffle and mushroom hunting (i.e. to what degree overharvesting is a concern). The report indicates that forest damage can occur with irresponsible foraging, but insists that further research on the topic is needed (Pilz and Molina 1996). More extensive work on the socio-cultural and economic impacts of practices and regulations around non-timber forest products was conducted by Eric Jones and Rebecca McClain for the Institute for Culture and Ecology in Portland, Oregon.

truffle production.[53] The first annual Oregon Truffle Festival, in 2007, had a similar commitment. A diverse array of figures from the Oregon truffling scene helped organize the inaugural festival— including commercial and amateur foragers, social researchers and forest mycologists such as David Pilz, Matt Trappe, Dan Luoma, Eric Jones and Frank Evans. While the main purpose of the festival was to improve the quality and reputation of Oregon truffles (including lessons on how to handle, prepare, and enjoy Oregon truffles), the initial OTF also included efforts to promote a wide array of "non-timber forest products," and to give representation to the many figures who research, make a living, and take enjoyment from Oregon's forests (see Jones et al. 2002). The backgrounds of these products and individuals showed a great diversity in aesthetic and socioeconomic class. Additionally, the educational side of the festival delve deeply into the science of truffles, mycorrhiza, and the ecology of Oregon's forest which truffles help sustain.[54] The festival celebrated existing regional expertise and practices while striving to develop new interest and markets around Oregon truffles. In short, the array of voices from the first few years of the OTF was broad. In addition to representation from forest mycologists and commercial foragers of non-timber forest products, NATS members showcased their organization. At current iterations of the OTF, some of these voices can still be heard at the "marketplace," a space where NATS still has a booth alongside sundry nonprofit organizations and for-profit companies who have an interest or sell products that deal with truffles and the forests from which they come. That said, later iterations of the OTF, as co-

---

[53] Mycologists invited to The Second Western Congress on Truffles at the Luther Burbank Center in Santa Rosa from December 3-5, 1987, include Gaston Guzman from the National Biological Survey of Mexico; J. Delmas from the Mushroom Research Station in Bordeaux France; Mario Honrubia from the University of Murcia, Spain; Nils Fries from the University of Uppsala in Sweden; Harry Thiers from San Francisco State University.

[54] For instance, lectures from the first OTF in 2007 include "Truffles in Context: A Mycological Overview," by Matt Trappe; "Truffle Diversity and Ecology in the Pacific Northwest," by Daniel Luoma; "Top hats, bicycles and mountain lions: tales of truffling pioneers in America," by Jim Trappe; "About NATS. No ...not pesky bugs,... the North American Truffling Society," by Frank Evans; "Why truffles are grown in plantations, but not some other edible forest mushrooms (so far)," by David Pilz.

organized by Charles Lefevre and Leslie Scott, have been limited in terms of who gets to lecture and exhibited their organization or company. Lefevre and Scott made the marketing decision to bring the festival's focus from one that included a diversity of voices and aesthetics around truffles and other non-timber forest products to a decidedly upper-class image of a few culinary truffles. This turned out to be a successful move in bringing popularity to the OTF. It helped helped attract funding for the truffle industry from large-figure investors such as Jim Bernau, co-founder and CEO of Willamette Valley Vineyards. Bernau was a critical figure in the creation of Oregon's wine industry; increasing popularity for Oregon's culinary truffles among a more affluent crowd, as represented at the OTF surely helped him see similar potential in Oregon's nascent truffle industry.[55]

As Lefevre and Scott's vision for how the industry should progress came to dominate, Oregon truffling culture became a decidedly conspicuous affair, promoted by a luxury aesthetic. Theirs was a marketing approach common to high-end food products, be it wine, truffles or artisan chocolate. These products tend to rely on, or borrow from, a European setting (for examples of French wine and chocolate, see Guy 2003; Terrio 2010). This approach caters to those with the money or popularity to set trends, in this case raising the social, and in turn economic, value of Oregon truffles. It is a continuation of the promotional work started by James Beard at the 1977 Mushroom and Man symposium.

With blind taste tests featuring Oregon and Italian whites, five-course dinners cooked by Michelin-starred chefs, and promotional shots of adorable Lagottos, Lefevre and Scott have been instrumental in bringing attention to Oregon truffles and in nurturing a culture that appreciates subtleties in the consumption and production of the truffles. They saw a particular route to spread

---

[55] Jim Bernau generously provided funding for a "feasibility report" on the Oregon truffle industry (Pilz et al. 2009).

the truffle bug to new and broader audiences, namely those with expendable income. Aware of the diminishing influence of truffle science in Corvallis, to ensure that Oregon remained known for its truffles, Lefevre and Scott pushed a new culture and aesthetic around the culinary truffle. The OTF was their primary tool in this pursuit. While the festival has expanded (and seemingly continues to), it has done wonders in spreading the word that Oregon truffles are there and are delicious (if you get them ripe and fresh and know how to cook with them).

The promotional strategy taken up by Lefevre and Scott, however, has not been without its downsides and contradictions. Lefevre, a graduate of the Forest Mycology team under the supervision of Randy Molina, clearly understood the importance of having (at least the perception) of a strong scientific presence to Oregon's truffle industry when he began to organize the festival. The trick was to feature those scientists and serious amateurs who built Corvallis into a global center for truffle science while also catering to (and striving to build) a new commercial culture that was (and is) often at odds with the modest, salt-of-the-earth qualities and values of eccentrism that figure prominently in Oregon's longer-standing truffle culture. This division limited who would play a role in curating the festival in subsequent years. Along similar lines, stark economic disparities have also been unavoidable. A few members of the Forest Mycology team who spoke at the first couple of OTFs told me how tensions arose with the third and fourth iterations of the festival, when researchers were no longer invited to present their work. Fair enough, these researchers told me: no need to repeatedly present the same research. Feelings of division and alienation reached a tipping point when the Corvallis truffle researchers were no longer given complimentary admission. As OTF admission fees rose and became unaffordable for many members of the Forest Mycology team (a good portion of whom worked on a contract-to-contract basis), they stopped attending the festival. Paywalls aside, as the festival became less about science and local environmental issues, and more about promoting a haute cuisine culture, Corvallis researchers and NATS members candidly told me that they no longer saw the scene as their own.[56]

A similar pattern of alienation occurred with many commercial foragers. They told me how the OTF began as a convenient and economically fruitful outlet for the sale of Oregon truffles. However, as the festival grew, concurrent with a broader interest in truffling (and the quick money it can bring), problems arose. The expansion of the OTF (and its many truffled meals) worked in tandem with other factors that brought a new wave of inexperienced foragers into Oregon's woods. In response to this concern, Lefevre pushes the narrative that raking is to blame (and is likewise to blame for the low-quality truffles that have flooded the market in the past few decades). Dogs, he insists, are the answer to responsible foraging and quality control. As a promotional tool, Lefevre's message has been incredibly successful. "Dogs-not-rakes" is a clean slogan, of which the savviest of tweeters would be proud. It has spread like wildfire.

When I sat down in a Portland bar with a forager who has been active since the 1980s, I gained a better understanding of the tension. Even before we ordered drinks the forager immediately launched into a discussion of how everyone is talking about dogs versus rakes. Despite the fact that he always hunts with his dog, he told me that the debate between rakes and dogs misses the underlying issue: we need to have people in the woods "who know what they're doing." This is the sentiment expressed by Jack Czarnacki, co-owner of the upscale Joel Palmer

---

[56] NATS still participates in the "Market Place" event at the OTF, but they keep their distance from the commercialism of the OTF. NATS is registered as a non-profit organization and leaders take this status seriously, even writing into their bylines that they will not partake in or promote commercial interests. This became a point of tension in 2008 when Charles Lefevre, then president of NATS, increasingly used his position to promote the festival. These efforts are plain to see in the NATS newsletters of that era. The newsletter was filled with ads for the OTF; once Lefevre stepped down as president, the ads ended.

House Restaurant, who likewise wants to see the discussion move away from which is the best tool to hunt truffles.

Another forager made the issue sound even more dire. To him, the problem is not so much people's lack of training as the fact that so many people digging in the woods today "don't [even] care to know" how to properly forage truffles. Mentioning Lefevre, he said, "Charlie has been one of my best customers." He then told me with a regretful tone that it is ironic that a truffle festival with an explicit mission to promote the dog-led harvesting of truffles is forced to buy raked truffes to meet ever increasing demand. Other foragers who sell to the OTF also told me that festival organizers cannot pay the premium price for dog-harvested truffles (which can be four times the price); they have pressured these foragers to come up with more truffles, even when there are simply too few ripe truffles to be found.[57] The problem is how to feed hundreds of mouths at once, to satisfy reservations made a year in advance. This does not allow for the vicissitudes and inconsistencies of truffle foraging. Those flying from around the world to spend hundreds of dollars on a five-course, truffle-infused dinner are not willing to hear that the truffles are not yet ripe, or that there is a shortage that particular year. The irony of serving unripe truffles is obvious: if gourmands who are accustomed to eating the famed European truffles fly to Oregon, willing to look past the Oregon truffles' stymied reputation, are met with the same unripe truffles that unfairly led to their poor reputation in the first place, the whole process will not have promoted but harmed Oregon's truffle industry.[58] Regardless of how well buyers for the

---

[57] Oregon trufflers have long met with pressure and temptation coming from companies that import and export gourmet food products. These buyers want larger quantities, and as truffles may be destined for jarred and prepared products, such as sauces and spreads, their standards are often low. I heard stories that stretch back to the 1980s, in which major European truffle brokers would buy Oregon Whites (which may sell for $80 a pound) and pass them off as Italian whites (which can go for $1000 a pound). But the problem seems to be more acute today, as there is an increasing number of buyers, and more widespread awareness that one can go into the woods and potentially make a few hundred dollars from a day spent raking forest duff.

[58] I should note that it is simply unrealistic that three meals a day for hundreds of attendees, all featuring Oregon truffles, would *not* include some bad truffles. Truffles are a highly perishable food. At the OTF I indeed tasted a few

OTF perform quality control (or depending on the quality they have to choose from) this broader initiative of what Sidney Mintz (1986) would call the "extensification" of Oregon's culinary truffles is bound to run into supply-end complications. The extensification of Oregon truffles involves a broadening of palates and cooking know-how beyond those within the social circles of truffle foragers, or who dine a select upscale restaurants.

As seen through the challenges faced by the OTF, those who organize large festivals (with thousands of attendees) that center around the consumption of a "wild" food are in a tight situation. As is the case with Oregon's culinary truffles, festivals designed to promote such products often do so when the ecologies of production for these products—namely ample skill, know-how and "feeling" for collecting the product at a sufficient quantity—are not yet in place, at least not at the scale demanded by the festival.

Heather Paxson (2013) uses the phrase "ecologies of production" to show the intertwined biological, social, epistemological, political and economic factors that make up artisanal cheesemaking. This includes the equipment, buildings and ruminants that fit perceptions of a post-pastoral farmstead and landscape, as well as microbes and enzymes that exist in the stomachs of ruminants and the rinds of cheese and that trigger the coagulation of milk and the regulation of cheese as it passes political boundaries (if pasteurization was not followed). For our current discussion, this also involves the skill of cheesemaking: the operation of machinery and the ability to read curds, in real-time, as they form. Boosters of Oregon's truffle industry recognize that a weak link in the ecology of production concerns a limited number of commercial foragers who hold care and feeling for the work of truffling. Oregon needs more such trufflers if it plans to hold still larger weekend events that require feeding

---

truffles that lacked or had an over-ripe flavor. In talking with others at the festival on the topic, my subjective judgement was confirmed. Such subpar truffles were the exception.

hundreds of people multiple truffled meals a day— meals which require the highest quality truffles.

______This need for greater skill and care amongst a larger number of willing and eager commercial trufflers highlights a key point: the OTF cannot run without the current scene of commercial trufflers, including those who use rakes. These foragers, most of whom I only got to know through derisive glosses of "meth heads" are the workers behind the fetishized product. The truffles that come from stands of trees available to those who make reservations at Bed and Breakfasts, or areas designated for truffling by the BLM, I argue, are of a different sort. Those who limit their truffling to such landscapes, as I found to be the case with numerous truffling newcomers with whom I spoke, do not build the same *feeling* for truffling as those who are part of Oregon's old guard of truffle hunters.

This raises the question: are boosters of Oregon's truffle industry merely out to increase the production of high-quality truffles, or are they out to create an entirely new truffle culture. In this chapter I have argued for the latter. I see a push for more dog training as part of an effort to reshape Oregon's truffle culture, and to increase truffle production in the process.

In Oregon skilled truffle foragers may be the bottleneck to the growth of the industry, but this is not the case for other regions that feature truffle production. Take for example, Italy, where there are plenty of human-dog teams that go out into the woods with generations' worth of knowledge on how and where to hunt for culinary truffles. On the other hand, what locations historically known for truffle production, such as Italy and France, have in short supply, Oregon has in spades: habitat in which truffles potentially grow. In fact, in Italy, forests known for high truffle production are protected explicitly for truffle hunting. The OTF is stuck in a catch-22: building a larger base of skilled foragers is precisely the goal of the festival; however, without such a community of foragers in place, the festival is limited in its ability to showcase the truffles in its effort to promote the industry.

What I saw in Oregon was not a simple process of increasing truffle production and extending awareness for the culinary value of Oregon truffles. I rather saw an aggressive promotional campaign aimed at an *extensification* of tastes, an attempt to alter what Oregon truffles mean to new and more expansive groups of gourmands. As Donald MacKenzie and colleagues (2007) write about economists whose theories and analyses of markets shape how these markets act (economists are far from outside observers of the economy), the OTF is an event that actively "performs" the expansion of tastes for the Oregon truffle. In this chapter I have analyzed this new taste not how it occurs in restaurants, but among a new group who seeks to enter the ecologies of truffle production. This is a group that desires to be seen with their truffle dogs, on prime truffle foraging grounds. This is a process that commoditizes truffle dogs (truffle dog training and forays led by expert human-dog teams is currently a good business in Oregon) as well as the most desirable spaces for truffle foraging. The displays on websites, newspapers and in social media are reminiscent of Thorstein Veblen's concept of *conspicuous leisure*, an activity for those with ample reserves of money and time that is precisely a symbol of such a socio-economic standing. The question is, does this commoditized consumption (even if they are actions that revolve around the "production" of truffles) allow for the vicissitudes of Oregon culinary truffles as they exist in their current ecology of production?

CONCLUSION

I have argued that the new truffle culture in Oregon is patently different from those who hunted truffles, a built a *feeling for the fungus*, in the latter half of the twentieth century. The activities and commodities (products and services) on offer at the OTF reflect a desire to be part of a new, popularized and often ostentatious image of truffles. To be sure, this new culture is something to be valued on its own. A small group of amateurs in pursuit of "the delights of the eccentric" are unlikely to last in such a state for long. The scientific truffle, although it still exists, has already become a shadow of the self it used to be. Jim LeComte, at the United States Bureau of Land Management (BLM) told me that he has been pressuring "higher-ups" to plant Douglas fir stands in ways that will optimize the growth of Oregon Whites. This, he argues, would be an economic boon both for Oregon's truffle industry and for his local branch of the federal agency. When my fieldwork took me to the meetings (often potlucks) of small woodland owner associations, I saw that these individuals and families who own between a dozen to a few hundred acres of land (almost always planted with Douglas fir, the "cash tree") are also interested in learning how to boost (and reap) the production of culinary truffles. To this end, several woodland owner associations have invited truffle experts to speak.

This comes back to the topic of landscape, or spaces of production, which has run throughout this chapter. The transition in Oregon's truffle culture follows a trend in which the spaces of hunting become less diverse. The old culture hunted in wooded areas not known to contain truffles at all (or minimally so). The new culture seems to narrow its efforts to woods tailored for or otherwise known to be rich in truffle production. Some of these areas are serendipitously rich in Oregon Whites; others have been managed for truffle production. Management of forests may involve clearing the forest floor, thinning or pruning in different ways. Most often, this is done in Douglas fir stands that would have been planted for timber, regardless of any non-timber forest product. Alternatively, spaces for the production of Oregon Whites might look more like the highly managed "orchards" that I will discuss in Chapter 2.[59] Here trees are planted and managed expressly for the production of truffles. In Oregon, these spaces exist more as a future potential than a current reality. To be sure, in order to supply the quantity and quality of truffles desired by the OTF and the current extensification of tastes for Oregon Whites, all of these landscapes and truffles ecologies of production will be needed.

The commercial foragers with whom I spoke are very aware of a proposed future in which Oregon's truffles are, to varying degrees, "tamed" (Hall et al. 2007). They are skeptical of this future. Even if such lands manicured for the production of Oregon Whites come into existence, they insist that the skill that it takes to go into vast forests—areas with uncharted truffle growth—and hunt truffles will still be in need; that is, the craft that they carry out with such devoted affection will not be rendered obsolete anytime soon.[60] One forager told me about the pain of "repeatedly" having his "heart broken" as he would present his bounty of dog-harvested truffles to chefs in Portland, only to have the chef disregard the value added by his and his dog's efforts and counter with a lowball price of maybe half the original offer. Bemoaning these counteroffers, he explained, "That is the price offered by others…who rake up everything in sight." Quite a few foragers, who have been at it for years, see the problem of unethical hunting as getting worse. These are people who have no qualms about putting in as many unripe

---

[59] If "tree farmers" were to strive to co-culture timber and truffles this would effectively create two phases of production where there had only been one. Truffles would be harvested while the trees mature; once mature, the trees become the crop. On a separate point, there have been attempts to sell Douglas fir trees whose roots have been inoculated with Oregon Whites, but the process has not been commercialized. This is likely due to the difficulty of the inoculation process as well as the low market price of Oregon's culinary truffles, as well as the abundant truffleing lands in Oregon. These factors render the expense of creating saplings inoculated with Oregon Whites economically unsound.

[60] Admittedly, those who lack what I am calling a feeling for the fungus, or for the hunt, and who care only about making a quick dollar, have long been hunting for truffles in Oregon. It is fair to say that this contingent of trufflers did not feel the need to talk with an anthropologist inquiring about the practice of truffling. My selection of informants was biased toward those who care about the practice of truffling and truffle ecologies.

truffles as possible (without detection), or who will rake the forest floor in a manner like the picture showed to me by Jim Trappe and Jim LeComte. Whether the problem is one of truffle quality or harm to the forested environment, these poor practices reveal a deeper ethical quandary: the lack of respect for one's work, or for the act of truffle hunting. The ethical problem becomes an economic concern when foragers with unripe truffles undercut those with high-quality truffles. This may happen at the back door of Portland restaurants, or when selling to buyers for the OTF. People need to "know what they're doing [in the woods]," this forager concluded. I take "knowing what they're doing" to address the feeling for the fungus that I have described.[61] In the case of enskillment/deskilling in community and public gardens, a group of English social researchers found that affect, care and ethics are necessary for the acquisition of skill (Gilbert 2013; Gieser 2014). I similarly argue that care and ethics, for truffles and their ecologies, is necessary when learning how to hunt responsibly for high-quality truffles in western Oregon.

The question remains: how can the economic value and awareness of Oregon truffles continue to grow while retaining the care and ethic required to sustain the *feeling for the truffle*? Do glossy promotional images of pure-bred dogs and white tablecloths necessarily erode the culture of epistemic generosity and labor ethic that initially made Corvallis the epicenter of truffling in North America? Or, as boosters of Oregon's truffle industry suggest, is the industry merely experiencing growing pains, an inevitable step on a path along which truffles in the American West will follow the region's wine industry? Can a path that leads to affluent tastes and conspicuous consumption—the molding of a culinary culture that fits the norms of global

---

[61] Bruno Latour (1999) makes a similar argument when he says that the debate on whether guns or people are responsible for murder misses the point. It is the *context* (a particular, situated assemblage of factors) that is deadly.

haute cuisine and food production—retain enough regional identity and sustain craft methods and small-scale modes of production?[62]

Sure, boosters say. Some people will join who have little feeling for the truffle (and have no interest in acquiring this feeling) and merely want a quick taste of the latest hype. But the festival and trademark truffle dogs will attract others who are interested in building a deeper relationship with truffles and the ecologies from which they come.

With public funding for truffle science a fraction of what it was when Jim Trappe or Randy Molina led the Forest Mycology team (and with Corvallis no longer a mecca for researchers in forest mycology), boosters see turning to industry—and specifically wealthy individuals who will back the new truffle industry in Oregon—as the only way to keep the truffle culture alive. More truffle dogs and lands tailored for truffle production will certainly advance the industry and improve quality-control issues, but they will not come close to supplying the quantity of truffles needed for expanding markets and festivals. The industry needs to take more serious steps to address the needs, shortcomings and skills of those commercial foragers currently at work in Oregon's forests—whether they use rakes or dogs.

CHAPTER 2: Old World Truffles in New World Lands: Cultivating Truffles and Selling a New Form of Leisure

Patrick Long is a semi-retired veterinarian based just outside of Corvallis, Oregon. He grew up on an industrial-sized farm in Kansas that included cattle and commodity crops, such as corn and soy. He moved to Oregon and came to own a successful veterinary practice for over three

---

[62] This is a perennial question asked by scholars of food and agriculture who work with varied products and practices (Grasseni 2009; Terrio 2000; Paxson 2013; Friedberg 2004).

decades before selling the "small animal" portion of the business. In the final years of the twentieth century, he took the proceeds from this sale and bought sixty acres of land between Interstate 5 and Corvallis. The land includes a pond, his house and a few rental properties. He leases out several dozen acres to a neighboring farmer (who grows animal feed), leaving him with a couple dozen acres on which to farm. As a veterinarian, Long still takes farm calls for large ruminants. He prefers to work with animals that are new to the region, such as llamas and alpacas. This is in line with his preference for working with "new and different" agricultural crops, be they plant or fungus. To his family back in Kansas, he has long been the "black sheep," finding pleasure in doing things outside of the status quo. In Oregon, this has become an economic strategy for Long, enabling him to carve out a living that is also gratifying. When he surveyed his newly acquired land, and thought about how best to farm a couple dozen acres, he knew that he could not raise cattle, or grow the commodity crops that he'd been familiar with in Kansas. As he told me, "I had to adapt to the new context." This meant finding niche crops. In the past two decades, he has grown heritage varieties of squash, tomatoes, rhubarb, and cardoons. Even with these crops in place, he still had a roughly ten-acre corner of his land that he wanted to cultivate. He sought a high-value crop that would satisfy his desire to experiment. An unlikely idea came to him on an American Airlines flight. Long was up in the air, reading the inflight magazine *American Way*. The June, 1999 edition had an article on the truffle industry. It was light reading that covered new production technologies that applied to the highly valued Perigord black truffle (*Tuber melanosporum*). The article boasted about the commercial availability of oak and hazelnut seedlings whose roots have been inoculated with *T. melanosporum* via a highly reliable process in a controlled environment in order to produce large quantities of seedlings that are free of contaminants. Since the high-tech trees had entered the market in the mid-1970s, the article continued, tens of thousands had been planted annually. So long as the climate was right, the inoculated seedlings—often called "truffle trees"—make it possible to grow the Mediterranean fungus outside of the Mediterranean region. This piqued Long's interest, and the notion of planting truffle trees stuck with him.

A sign posted on Interstate 5 just outside of Salem Oregon regularly reminded Long that his land lay just south of the 45th parallel. He checked the latitude of Southern France. It was the same. The Willamette Valley gets more rain than Southern France, but it is similar in that it has dry summers and winters that rarely experience deep freezes. These analogous environmental factors convinced Long to try and grow melanosporum. With the realization that Western Oregon is rich in truffle and mycological culture, Long was determined to take up truffle farming. The small college town just down the road had a glut of world-class truffle expertise, led by Jim Trappe, whose cat Long had cared for at his veterinary practice (Long had also taken care of a truffle dog that belonged to a relative of Trappe's). With these experts nearby, he figured he could reach out to them to ask for guidance on the complexities of managing the mycorrhizal symbiosis, should the need arise. When I first met Long and asked why he decided to grow truffles, he spoke about "sustainable" farming. His definition began with a need to be frugal in farming, in the sense of drawing from local knowledge and material resources, while producing a crop that could be sold locally (not to mention developing a new system of farming and a new crop for region farmers to grow). The local resources proved to be amenable to his truffle farming.

Long called the Forest Mycology Team at the USDA Forest Service in Corvallis soon after reading the inflight magazine. He asked the receptionist for James Trappe and was told that the famed mycologist was away in Australia, collecting truffles. Long requested to speak with another mycologist. For one reason or another, the inquiry went to a graduate student working on matsutake mushrooms in Oregon's forests. This was Charles Lefevre. Long asked Lefevre if he would inoculate the roots of a few hundred saplings with the spores of *Tuber melanosporum*, and how much he might charge. Lefevre, never having worked with truffles in such a way, turned down the request. He recommended that Long reach out to Tom Michaels, an old student of Trappe's who had performed precisely this job, and was now growing melanosporum in Tennessee.

Tom Michaels's dissertation research was on new techniques to culture and grow *Tuber melanosporum* on trees in the American West. After graduation, he followed his family to Tennessee, where his wife had taken a job. When I asked about his motive for truffle farming, he said that he needed a hobby "outside of the house." He quipped about being a stay-at-home dad who turned to farming in order to "keep his sanity." Michaels had little personal experience farming truffles, but he had training in the ecology of truffles, he knew how to create truffle trees, and he knew how to raise plants that harbor specific species of mycorrhizal fungi (which is, fundamentally, what mycorrhizal researchers do when they experiment).[63] In short, Michaels was rich in the rather esoteric branches of knowledge required to farm truffles. Michaels designed and installed his orchard in Tennessee, and by the late 1990s was reaping annual harvests of melanosporum from a few hundred hazelnut trees.

Since the 1980s, a handful of North American growers have claimed to have harvested melanosporum, but their successes have been inconsistent, not very well-documented, and oftentimes have not been entirely credible. Michaels, however, gave the continent its first well-documented and consistent case of melanosporum production. For over a decade, he reaped

---

[63] Moreover, Michaels had a previous career cultivating mushrooms (those that live on dead organic matter rather than roots) on a family mushroom farm in California.

yields that increased with each season—and then Eastern filbert blight began to kill his trees. Before this, during his productive streak, Michaels hosted news reporters on his orchard who covered his truffle harvests and sales of truffles to top chefs on the East Coast.[64]

Michaels initially agreed to sell inoculated truffle seedlings to Long, but then hit a regulatory snag. Eastern filbert blight had begun to expand to the American West; to curb the blight, the State of Oregon banned hazelnut trees from crossing into its jurisdiction. Once the venture with Michaels collapsed, Long, ever persistent, returned to his original idea and wrote a subsequent email to Lefevre. Would he reconsider? The truffle trees had to be produced in Oregon. The original email chain between Long and Lefevre shows Lefevre's initial hesitance to inoculate trees in Oregon with a Mediterranean fungus. Lefevre writes, "in full honesty… [I cannot say] how successful the inoculation will be." In a later email, after agreeing to give it a try, Lefevre expresses excitement over the high colonization rate of the first batch of truffle trees.

This collaboration between Long and Lefevre would be the catalyst for a network of people interested in farming melanosporum in Oregon.[65] Shortly after inoculating the trees for Long, Lefevre founded New World Truffieres, what may still be the largest truffle-tree nursery in North America. Long, for his part, has become an exemplary case of melanosporum farming in Oregon. There are other successful growers in the region, but Long's openness about which

---

[64] Shortly after Michaels' success began, a melanosporum farm in North Carolina came into production. The owners, Rick and Jane Smith, even had Martha Stewart come to the orchard to film a segment on truffle farming.

[65] The French-American entrepreneur Francois Picart was a precursor to the current network of farmers and nurserymen. In the 1970s, Picart traveled up and down the Pacific Coast selling escargot. When he caught wind of a French company, AgriTruffle, that was selling truffle trees, he convinced AgriTruffe's owners to let him sell the trees in America. In the 1980s and 1990s, he added truffle trees to his offerings. He sold trees that grew into an orchard that produced melanosporum in Mendocino, California. He also allegedly sold trees to landowners in Oregon. However, as these were private transactions that occurred in secrecy, the veracity of such claims, let alone the extent to which the orchards produced melanosporum, as far as I could investigate, remains conjecture. After Picart managed one (or a few) truffle farms in Texas that never ended up producing, he got out of the business and went on to found a successful family-run chain of chain of Texas BBQ restaurants in France, called Texas Roadhouse.

orchard management techniques have worked—and failed—on his land, and his willingness to bring groups of visitors to his orchard, are second to none. Long's sense of experimentation and hard work led to increasingly higher truffle yields during my years of fieldwork in Oregon (2015-2019).

In this chapter, I hold up Long as representative of one approach to truffle farming. I argue that Long's approach to truffle farming follows a *style of engagement* with antecedents in nineteenth-century France. A truffle farmer in France described this approach to me as a *culture d'attente* (culture of waiting), and stressed that this culture is unique in agriculture. After visiting and occasionally working with truffle farmers in Oregon and Southern France, I indeed came to see when and how a truffle farmer must *wait*, and learn to observe the indeterminacies of truffle growth, rather than directly manage them. But I also came to see that while this perception of waiting captures a necessary quality of truffle farming, it also ignores or downplays what goes into this waiting. As Manpreet Janeja and Andreas Bandak (2018) demonstrate in their edited volume *Ethnographies of Waiting* which explores the question of "waiting" more generally, I argue that this waiting is not passive but active. I identified a "culture of waiting" among many growers, but I also noticed the incredible discipline and labor that was part of this waiting. Whether it is observation (attuning to) or experimentation (tinkering with), I found that successful truffle farmers are in continual engagement with the ongoing changes on their land. Waiting is indeed part of this engagement, but this is a waiting characterized by vigilance. Enskilled noticing is followed by an often tacit and improvisatory decision-making process that dictates how and when a farmer will tend to the orchard. What makes truffle farmers such as Long successful, I argue, is not waiting but *engaged waiting*.

These growers are active, but one could easily make a cursory judgement of their actions as lax or leisurely. They seem to saunter through the orchard and casually tinker in small and unimportant ways. They lightly prune trees, unclog or fine-tune irrigation lines, check for pest damage, tweak baiting schemes, clear ground cover, and poke underground for signs of nascent truffles. By appearances alone, this work is done with the carefree manner of someone who has a separate crop, or a separate job, that provides a livelihood; or someone who is comfortably retired or half-heartedly pursuing a second career (and won't suffer—thanks to accrued personal savings—should their crop fail).

Truffle farming requires what Pierre Bourdieu (1984) refers to as economic and cultural disposition. Farmers must have disposable savings—from an earlier career or inheritance—in combination with the willingness and ability to engage in a highly technical form of farming that requires extended periods of trial and error. As such, the concept of *leisure* was unavoidable in my fieldwork: growers and industry insiders spoke of the luxury of being able to labor within one's orchard for a decade without any economic return, while those with only the vaguest idea of what truffle farming entails referred more to romanticized notions of light and occasional work within bucolic orchards. In all cases, leisure indexes extended time-frames, and a *culture d'attente* that takes this timescape in stride. The ability to have leisurely time-frames connects with a history of farming melanosporum in the South of France, on abandoned or marginal land. In nineteenth-century France, most who managed truffle orchards had another livelihood (Van Vleet 2018). A truffle-less season would not necessarily lead to privation. Moreover, as melanosporum grows naturally in the South of France, orchard management was minimal: a truffle farmer merely needed to maintain basic growth parameters, which entailed little more than tree pruning and, in some cases, weeding plants thought to prevent the growth of melanosporum.[66] This may not have been optimized production, but it was a non-intensive style of farming that was somewhat separate from one's principal livelihood and thus could be approached with a certain leisure.[67]

The ability to work with extended time-frames is often a result of accrued economic capital and privilege. Historically, in melanosporum's natural habitat, the only capital a prospective truffle grower needed was disposable land. Today, with high-quality truffle trees and mechanized irrigation systems that are seen as indispensable, truffle farming requires a fair amount of investment. This is even more true in areas such as Western Oregon, where the soil needs to be prepared in a way that mimics Southern France's (friable, well-draining and with a high pH). Another prerequisite form of capital is knowledge. This is not just any knowledge but a rare combination of experiential agrarian know-how, a familiarity with soil microbiology (mycorrhizal science), and, above all, an experimental inquisitiveness that drives one to continually learn more about truffle farming, amidst failure. Be it land, knowledge, or expendable money and time, these prerequisites (or dispositions, following Bourdieu's analytical framework) to truffle farming make the pursuit one imbued with privilege.

Truffle farming in North America has yet to provide anyone with a viable livelihood. Although truffle farms and truffle businesses have been set up in North America since the 1980s, only in the past few years has truffle farming become a feasible investment for those venture capitalists willing to deal with the highest of risks (and rewards). Thus far, the few farmers who

---

[66] This includes weeding plants not known to grow with melanosporum, or those which a farmer might correlate with spaces on the orchard where truffles are not found. In some cases, orchard management involves light soil work, or even light irrigation during extended droughts.

[67] This is not to say that some did not meticulously manage orchards with complex irrigation systems, severe pruning schemes, and the regular "re-seeding" of land with truffle spores. Still, as archival documents show (Rousseau 1866), it was more common for truffle farming to occur as an activity done on the side, within a leisurely time-frame and with minimal resources. This led to a tradition of truffle farming that required minimal labor and barely disturbed the land, even enhancing what today is called biodiversity. Today, many in France's truffle industry tout this legacy, and use it to call truffle farming one of the most eco-friendly forms of agriculture. See more below.

have succeeded, such as Michaels and Long, have been able to supplant monetary investment with rich and diverse know-how, the willingness to experiment (and fail), and the patience to work within a leisurely time-frame. For instance, Michaels cut back on costs by creating his own truffle trees; his doctoral work in mycorrhizal science and his earlier experience on mushroom farms also enabled him to improvise his way through orchard management. Michaels's expendable time, or leisure time, came in the form of a spouse with a well-paying job; he was a stay-at-home dad who managed to work in the orchard with kids in tow. He did not have the financial pressure to produce truffles as quickly as possible.

Still, if this leisure is separate from livelihood, it is not completely separate from economic motive. All growers whom I met made it clear that the *potential* (no matter how distant or unlikely) for profit contributed to their decision to grow truffles. Stephen Gudeman (2008) writes of a dialectic, a tension between mutualistic and market influences in any culture or society. Among the growers with whom I spoke, I found great variance in their motives to farm truffles. Economic profit could be a high or a low motivating factor. Often I found it to be overshadowed by the joy of experimentation, or the reward of being an "early adopter" in an up-and-coming industry.[68]

Through the concept of "entrepreneurial leisure," Nikol Beckham discusses the "transformation of leisure pursuits into businesses and occupations" (2017; 95). Among truffle farmers, I did not find a transformation from one realm (avocation) to another (livelihood). Rather, as one Oregon truffle farmer put it, truffle farming is a leisurely pursuit that "happens to

---

[68] There are those who buy a few truffle trees to plant in their backyard, and who are largely interested in growing "trees with a story, " as one nursery owner put it. Among those whom I met, most sought the novelty of telling houseguests that they have truffle trees; they often hold minimal expectation that they will ever find truffles. Most conduct little to no ongoing management of the trees or soil at all. I do not discuss this contingent of growers in this chapter.

also make money." This is not to reduce truffle farmers to a group of "resourceful individuals" who have found a way to "get paid to play," as Beckham heard among craft beer brewers (*ibid.*). The truffle farmers whom I got to know are highly passionate about the non-economic purposes of their work, which range from contributing to truffle science, to developing a new industry for rural Oregon, to land stewardship. The importance of what Gudeman would call non-market forces is evident in the fact that farming Mediterranean truffles in North America has grown rapidly despite open knowledge that most orchards only produce truffles sporadically (if at all).[69] When I spoke with farmers who manage orchards that are under-producing or yet to produce, they nonetheless demonstrated thorough satisfaction with the pursuit.

This chapter discusses the non-economic values that come with farming truffles in Oregon. Oregon has a long reputation as a state with ample natural "resources"[70]; these include the fertile soils of the Willamette Valley and the moist and temperate climate of Western Oregon. These conditions have made the region a national (and global) center for the production of grass seed, nurseries for trees and herbaceous plants, and all manner of specialty crops (Robbins 1997). Oregon's wine industry has also boomed via its reputation for small yet high-quality vineyards (Woody and Schmidt 2013). While boosters of Oregon truffles draw on these perceptions of bounty and the bucolic, they also feed the desires of second-career farmers to start a truffle orchard in Western Oregon. Moreover, they dovetail with an image that stretches back to the nineteenth century in the South of France in which truffle farming was seen as an act of

---

[69] That said, during the end of my fieldwork, especially from 2017 to 2019, the number of producing orchards in North America had risen exponentially; see more below.

[70] Neil Evernden (1985) wrote about "resourcism" or the tendency to view the natural world as resources for human use. For a rebuttal to such an environmentalist critique on how nature is perceived or enacted, see Richard White's (1996) essay "Are You an Environmentalist or Do You Work for a Living?"

patrimoine, a way to "improve" the land via reforestation while producing a crop of high cultural value.[71]

But, just as I observed in Chapter 1 (with the foraging of culinary truffles in Oregon's Douglas fir forests), a contingent of melanosporum farmers in Oregon now seek to put the budding industry on a different track. Whereas Long's approach of engaged waiting was once seen as exemplary truffle production, this new contingent of growers, who have what I describe as a professional ethic, no longer accept the extended time-frames filled with experimental tinkering that culminate in the embodied know-how. This new group of farmers pour more money into their orchards, and turn to outside expertise (often consultants coming from distant continents) in an effort to produce melanosporum as quickly and consistently as possible. They bask in the prospect of being "early adopters" who will be recognized as having set the course for a thriving industry of melanosporum production in Oregon (and North America more generally). However, as I will show, this more aggressive style of engaging a truffle orchard carries implications for how "sustainable" an orchard can be—both in terms of a grower's personal rewards, and in terms of truffle farming as an "eco-friendly" activity.

Chapter Roadmap

Part I of this chapter opens in France, with a historical look at the products and knowledge practices now used to grow melanosporum in Oregon today. I begin with the creation of the technology that lies at the center of contemporary truffle production: truffle trees. I show how this technology has mixed (and failed to mix) with efforts to revive practices of truffle farming in France that were lost in the destruction of the two World Wars. Historically, truffle farming in

---

[71] For brief histories of truffle production and its meaning among the French, see Nowak (2015) and Rebière (1967).

France was not resource- or labor-intensive—it was largely a side activity, something to do with marginal land. I show how this approach has moved to Oregon in the form of *engaged waiting*, which I describe as a way to make productive use of broad time-frames (leisurely time-frames) for those of privileged circumstances. I argue that leisure, in this case, performs important scientific, agronomic, and community-building work.

Part II incorporates truffle biology into my discussion of styles of truffle orchard management. Engaged waiting is not only shaped by agrarian tradition and economic pursuits, but also by the unique biology of truffles, which can live for decades belowground in a vegetative state (following an asexual life cycle). This unique biology enables flexibility in truffle orchard management, but it can also serve as an opportunity to be neglectful of orchard management. I describe truffle farming as the creation of "truffle zones," which allow the fungus to survive underground for decades. Once the zone is created, a farmer must then get the fungus to produce fruit (the truffles). This is what makes truffle farming difficult and shrouded in mystique. How melanosporum has sex (its sexual life cycle) is a process that continues to confound truffle farmer and researcher alike. I describe how this difficulty in getting melanosporum to fruit with consistency has led to collaborations—transfers of knowledge—in which agronomic and agrarian approaches and know-how are treated with parity. Truffle farming today is an industry in which researchers learn from farmers, just as much as the other way around.

Part III concerns a style of orchard management that departs from engaged waiting. I conducted fieldwork during a nascent and burgeoning time of melanosporum production in Oregon (and North America in general). As such, I witnessed engaged waiting shift from an exemplary to contentious style of orchard management. The tinkering of engaged waiting came into competition with a more professional manner of farming truffles. The latter group seeks a certain level of standardization in truffle farming; they have a professional ethic (and identity) that they see as necessary if Oregon is to become a reputable location for melanosporum farming.[72] Those within this professional contingent strive to change the perception that truffle farming is a project of uncertain tinkering that requires long periods of waiting; the philosophy behind engaged waiting has, in their minds, fueled the erroneous belief that truffle farming is a matter of "planting and waiting." The latest truffle science and farming know-how, they argue, make such practices unnecessary. And while this more professionally oriented group admits that there are individuals such as Long who manage to produce truffles in frugal and ad hoc ways, they hold that the problem is that such individuals are exceedingly rare—a thriving truffle farming industry cannot be based on an approach to orchard management such as engaged waiting. These professionals accept that even a decade ago engaged waiting played an instrumental role in what they see as the development of a truffle farming industry; today, however, the approach only exacerbates what they see as a misleading perception that has truffle farming as "hands-off" and requiring "minimal labor." Instead of a driver of new methods in truffle farming, the new professionals (as I will call them) see engaged waiting as a form of inertia that threatens to halt the progress that is needed in Oregon's (and North America's) truffle industry.

In the final section of the chapter, a paradox comes to the fore. Those growers (and boosters) who seek to professionalize the truffle industry and do away with the leisure of engaged waiting turn precisely to this image of leisure when trying to market or give "added

---

[72] With melanosporum farming expanding around the globe, many regions and countries now compete for a reputation as the best location for farming Mediterranean truffles beyond the Mediterranean region. North America, Northern California, and Appalachia seek such a reputation. Globally, locations such as Western Australia, South Africa, and Chile are trying to build truffle farming industries.

value" to regional truffle products. They seek to market an *ecology of production* in which a small or mid-sized truffle farmer follows an approach such as engaged waiting. This is a romanticized image of leisurely truffle production that fuels perceptions in which truffles are grown with care by only the most inventive of farmers who joyfully labor in bucolic landscapes. In addition to justifying higher prices for the truffles themselves, this rose-tinted perception of a truffle-producing lifestyle fuels an industry in high-end agro-tourism (farm dinners or overnight stays) and turn-key truffle orchards (for those seeking a "lifestyle" change who want to farm themselves).

For some, truffle farming is not only about truffles, it is also a form of land stewardship and biodiversity enhancement. Here we find an important distinction between truffle farming in Southern France and the Pacific Northwest. In France, the history of truffle farming as a supplemental activity for an already productive farmer (often a viticulturist)—a way to make use of marginal land—is now sold with an argument for human health and biodiversity. Melanosporum, boosters of France's truffle industry argue, is a low-input crop that allows for a high amount of agro-biodiversity (Sourzat 2004). Unlike grapevines that require high amounts of pesticides (and often abut villages, making pesticide drift a public-health concern), truffle trees require no inputs aside from occasional irrigation. Moreover, they encourage the "reforestation" of land that would otherwise remain without trees. Arguments for biodiversity come from the fact that truffle orchards in France—which can include tree species such as oak, hazelnut, hornbeam and pine—are often favorable grounds for the flourishing of regional wildflowers and other herbaceous ground cover.

Boosters of melanosporum production in Oregon try to borrow these arguments of reforestation and biodiversity enhancement from France (i.e. these perceptions of manifold benefits to truffle production). But as I heard from truffle scientists in the region, the production of Mediterranean truffles in the Pacific Northwest is anything but a form of stewarding land and conserving biodiversity. This is especially the case with the more mechanized and resource-intensive forms of truffle farming promoted by those professionally oriented growers who reject engaged waiting. As this professional group seeks to do away with the extended time-frames of truffle production, it puts more pressure on orchard ecologies to act in specific ways. Achieving accelerated and more consistent truffle production (on orchards that tend to increase in size) requires greater efforts to manipulate soil and limit biodiversity via the control of pests that threaten truffle growth and quality (groundhogs, ground squirrels, and slugs are just a few pests commonly confronted in Oregon with which French growers rarely have to contend). Oregon growers must bring many tons of lime onto their orchard (and must continue to do so, in smaller quantities, on a regular basis) in order to maintain a high soil pH; many have to seasonally till in order to make soils well-draining, like those where melanosporum flourishes in Southern France. As occurs with Oregon White truffles, careful marketing accompanies the growth of Oregon's industry in melanosporum farming. Industry boosters are well aware of the need to maintain a perception of truffle farming as eco-friendly and human-scaled (see, Berry 1996; Schumacher 1989), an image used in other niche agricultural markets in Oregon Oregon (Pilz et al. 2009).

PART I: Contemporary Truffle Farming Takes Shape

Truffle Tree Technology

Clermont-Ferrand is the major city in France's *Massif Central*, a mountainous and not densely populated highland, due south of Paris. Famous for tire manufacturing, the city is also the site of a major research center for France's National Institute for Agricultural Research (INRA). Research on animal agriculture dominates at the Clermont-Ferrand branch of INRA. In the 1970s, the center also hosted an important group of mycologists, who, in a friendly competition with Italian researchers, were the first to industrialize a new technology that they hoped would bring consistency to melanosporum farming.[73] They standardized a procedure used by mycorrhizologists in labs, greenhouses and experimental fields for much of the twentieth century (Murat 2015). This was a process of inoculating the roots of tree seedlings in a controlled greenhouse environment (often in near-sterile growth media). It guaranteed that melanosporum "infected" the root system to a high degree, to the absence of competing soil-dwelling microbes. Most importantly, this procedure for creating "truffle trees" (*arbres mycorhizés*) was scalable. In 1973, INRA researchers founded a company, AgriTruffe, to manage the production and sales of truffle trees. Over 300,000 INRA-certified truffle trees have been planted annually, for over twenty years; that is about 1,000 hectares planted annually (Sourzat 2017).

These truffle trees have proven to be a highly reliable technology. In Oregon, when I had the opportunity to unearth and view under a dissecting microscope the roots of truffle trees that had been in the ground for ten or fifteen years, the tell-tale signs of melanosporum were present.[74] Researchers in Oregon told me of similar observations, even with trees on orchards that were hardly managed, or which never came into production (although in Southern France,

---

[73] Some mycologists around at the time described the Italian and French teams engaged in a rather chauvinistic competition. There are differing views over who first came up with the technology. Some think that the Italians first perfected the concept of truffle trees, while the French industrialized the process. For more on the creation of truffle trees, see Murat (2015).

[74] After a few years of looking at roots for evidence of mycorrhizal fungi with various mycological teams (from Massachusetts to Oregon to eastern France), I was able to conduct the analysis on my own (with a high level of confidence in most cases). Visualizing ectomycorrhizae as they form on root-tips only requires a dissecting microscope. One can even get a general impression of ectomycorrhizal morphology with the naked eye (or a jeweler's lens). The tell-tale signs of melanosporum are black, club-like structures that cover root-tips. There are some look-alike fungal species that have a similar morphology, but, especially in Oregon, melanosporum on root-tips tends to stand out.

unmanaged orchards tend to be overtaken by fungal species that compete with melanosporum). Truffle trees were meant to be a technology that is one part of a larger push to revive France's production of melanosporum. This effort began in the 1960s with the formation of a series of truffle growers' associations (Olivier 2018). These associations aimed to cobble together the most effective techniques of truffle orchard management. They promoted guidelines for establishing and maintaining truffle orchards, of which truffle trees were just one component. Before long, however, optimistic and often prospective growers—not to mention nursery owners eager to sell truffle trees—took the new high-tech trees as a sufficient condition for truffle production, failing to take seriously the need for farmer enginuity.

France's "Golden Age" of Truffle Production

France's early truffle growers' associations formed as a way to revive the country's truffle industry. From the mid-nineteenth century until World War I, an era now known as the "Golden Age" of truffle production, France was producing annual totals of over one thousand tons of truffles. Some estimates, for years just following the turn of the twentieth century, are as high as two-thousand tons (Baragatti et al. 2019). The reasons for this vast increase in production are the same as those for its decline: changes in the landscape that come with changing patterns of agrarian practice and migrations. Most truffle researchers cite the French Revolution as the first event that led to a boom in truffle production. The upheaval of social and government codes that had long protected forests across the French countryside were gone, and widespread deforestation followed (Sourzat 2017). This was followed in the mid-nineteenth century by the decimation of France's wine industry due to the phylloxera blight. Thousands of acres of vineyards were left and abandoned, and even burned. These factors led to an opening up of landscapes which, in many cases, became young oak forests.

Melanosporum is what biologists call a "pioneering" species: it thrives in young forests, and grows well with the oak trees that flourished across Southern France. This resonates with Anna Tsing's (2015) discussion on how matsutake mushrooms flourish in forests that are regularly walked and worked by people, a form of disturbance that allows some organisms to live and not others. Tsing uses the Japanese term *satoyama*, which names the sort of woodland that is regularly worked by people and in which matsutake flourish. She calls these "liveable" forests that provide charcol, firewood, livestock grazing, and the collection of edible plants and fungi. When you take away the people, the ecology changes, and matsutake no longer fruit with regularity. A similar phenomenon is at play with melanosporum. With strong agrarian communities in Provence and what is now the midi-Pyrenee region—groups of people who were active in forests, collecting firewood and raising livestock—the forest retained the thinned and open quality that melanosporum growers today aim to re-create (Le Tacon 2017). These conditions continued throughout France's "Golden Age" of truffle production, up until the beginning of the first World War. With the war-time displacement of agrarian communities, and broader trends of rural-urban migration and the industrialization of farming practices, by the mid-twentieth century, many of France's oak forests were neglected; they became environments favorable to a new host of forest-dwelling fungi rather than melanosporum (Sourzat 2017).[75] The effect was drastic: since postwar France, annual production of melanosporum has averaged 40-

---

[75] For other researchers, climate change, namely Mediterranean summers that are getting drier and hotter, has been and will remain the leading factor behind the decline of melanosporum habitat and production (Thomas and Büntgen 2019).

50 tons (the 2003-04 season only reached 10 tons, while the 1977-78 reached 100)—a precipitous drop from production numbers in the thousands of tons (*ibid.*).

France's truffle-grower associations began with a mission to gather the truffle farming know-how that was scattered and lost during the two World Wars and the industrialization of the French countryside. They would survey the wide array of truffle-farming practices used across regions and across the decades, to separate the wheat from the chaff, and find which methods were effective and could be prescribed to growers today. This has proven to be a tall task, for these environments have not remained static. As landscapes go through continual changes, it is hard to know precisely what environmental conditions or what management practices allowed melanosporum (and not competing fungi) to flourish. Even where melanosporum fruited in abundance generations ago, growers today struggle to produce inconsistent, low quantities of the truffle.

With the turn of the twentieth century, melanosporum farming spread far beyond the Mediterranean. Aside from select individuals and regions (Manjimup, Australia; the Serrion Plateau of Spain), however, initiatives to farm the truffle have been inconsistent at best. This trend holds despite advances in understanding the biology of melanosporum (for work on the genome and life cycles of melanosporum, see Martin [2011]; Rubini et al. [2014]; Le Tacon et al. 2016]), and amid the continued production of high quality truffle trees. Despite advances in truffle tree production and increasingly known growth parameters of melanosporum, still the truffle farming industry is slow to move beyond sporadic cases of success. Growers and industry insiders account for what success occurs through tacit and embodied forms of know-how found in select individuals. With agronomic and agrarian forms of knowing and practicing both greatly limited, each in their own way, truffle farming rests in a temporary balance between standardization and context-dependency. Numerous orchards serve as proof-of-concept for various locales and scales of production. But at the same time, ample unknowns necessitate personalized (and regionalized) experimentation, which often comes with enough delays and setbacks to bankrupt those who rely on the activity for their livelihood. Still there is enough potential to satisfy venture-capital investment. And individual cases of success continue to surprise researchers, venerable truffle farmers, and technicians alike. I saw this at play one wet winter day when I walked the heavy Willamette Valley soils of Long's orchard with a leading French agronomist and truffle expert. This French researcher looked down at the mud that clung tenaciously to his boots, a clear signal of high clay content in a soil that would not be described as well-draining, then stated simple: "*incroyable.*" Switching to English, he explained, "I can't believe melanosporum grows here."

Passionate growers, who rarely hold degrees in the biological sciences and often come to melanosporum farming from other careers, increasingly break expectations such as the French researcher's. These select individual farmers have managed to grow melanosporum in environments thought inhospitable to the fungus, such as Vancouver Island, Canada, and the Atlas Mountains of Morocco. That more and more farmers, from around the world, are finding success farming melanosporum, and that attempts to grow melanosporum are still more commonly met with failure, point to the unique (and temporary) epistemic state of truffle farming. It is a project filled with known growth parameters and indeterminacies alike. Theses knowns and unknowns coexist for anyone who studies the biology of truffles or practices truffle farming—this is why the cultivation of truffles brings together, on an equal epistemic plateau, lab-based researchers and farmers without any scientific training.

Culture d'attente

Despite melanosporum's cultivation around the world, that consistent production remains limited to select individuals and select orchards shows that even having high-quality truffle trees and following well-known growth parameters are not sufficient conditions for success. Consequently, people in and around the truffle industry are drawn to the notion of a special disposition or comportment that must be shared by successful truffle farmers. In Burgundy, France, a region (historically) north of the fungus's "natural" habitat, a melanosporum grower told me about what he saw as a learned set of skills and a built disposition that is unique and even necessary to truffle farming. He said this while we were riding in his old hatchback car with his two truffle dogs (small white mutts, not lagotto romagnolos) yapping away in the back. We were headed south from Nuits-Saint-Georges, looking out at a gentle hillside that contained some of the world's most expensive wine grape real estate. I asked the truffle grower if he could estimate the percentage of vineyard managers who also cared for truffle orchards. We had already visited two truffle orchards that were situated on vast vineyards. Although the two crops are historical companions, he noted that it is rare to find someone who can effectively care for both crops. Truffle farming, he explained, contains its own "*culture d'attente*." He went on to describe the extended time-frames and inordinate amount of uncertainty that has always been a part of truffle farming; it forces one to relinquish a certain amount of control. Despite it being the summer—a season in which truffle farming is supposed to be at its most low-maintenance and "hands off"—the grower spent a few hours tending to trees and gates, checking ground cover, and speaking with neighboring farmers (with harvesting still months away, the dogs had no official task, but excitedly sniffed around nonetheless). He explained how a truffle grower must always remain attuned to layers of ecological cues that indicate how a truffle is growing. But building up these skills of noticing takes years, often decades. Even when one becomes adept at reading the cues, still much uncertainty remains. This is why Tom Micheals, when speaking to prospective truffle growers, insists that the largest challenge of truffle farming does not concern seasonal labor or any understanding of soil analysis or the mechanics of the mycorrhizal symbiosis. The most difficult part is psychological: the ability to deal with years of "free-floating anxiety."

But one does not deal with free-floating anxiety by passively waiting. I understand why my French informant would emphasize that pleasurably farming truffles requires a degree of letting go (disengagement), and simply accepting the process of waiting. But his words expressed a passivity that his actions belied. He was constantly active, although his actions that day on the orchard were not preplanned. He noticed and made adjustments based on what he saw, in real time; in other words, his activities were not work that one could expect to do during the latter half of August specifically. He held knowledge—stories even—that pertained to the production of specific trees (i.e. where exactly truffles were found in relation to trees, at what depth, and in what shape); he noted how production in particular swaths of soil changed from year to year; he noted patterns in the depth at which truffles were found and how this correlated with soil texture and his tilling regime; he noted the growth rate of individual trees and how phases of growth matched with truffle yield; he also noted ways in which neighbors were willing to help (fixing or opening orchard gates that keep out and let in certain mammals; tending to irrigation lines) or how they presented challenges (pesticide drift from neighboring vineyards, or, inversely, insects and pathogenic fungi that multiply on vast monocultures of grapevines and might spread to his trees). Like any farmer, he had to hold these many histories and factors in mind while making in-the-moment decisions about how much to irrigate, till or prune, depending on weather conditions, the age and health of trees, and so on. While this complex, improvisatory skill is common to farming in general (see Harper 2001), it reaches new heights (if it is not different in kind) with truffle farming.

Perhaps it was out of modesty that the Burgundian truffle farmer spoke of a culture of waiting. He may have downplayed his embodied know-how, and not have been aware of the rich tacit knowledge (Collins 2010) that he puts into producing truffles. Either way, he brought my attention to the balance of hands-on and hands-off work, noticing and tinkering, observing and acting, with which any truffle farmer must continually engage. This is a balance of engagement and disengagement, not unlike what Matei Candea (2010) describes with researchers who care for meerkats. Truffle farming involves a mix of being meticulous and loose, which the Burgundian truffle grower feels is necessary for the health of the farmer as well as the truffles (here, again, is Michaels's point on being able to manage free-floating anxiety). "We don't know everything," was his polite way of saying that truffle science leaves a lot to be desired. This brings a tension (if not contradiction) to the art of truffle farming: one must continually experiment and improvise new management methods in response to the ever-changing orchard, as components of it thrive or wither; at the same time, a grower must retain a sense of distance, of separation that allows for the *witnessing* of processes whose mechanics and components are not known but must be steered nonetheless.

Following my visit to truffle orchards in Burgundy, upon returning to Oregon, I paid close attention to how truffle farmers waited. What kind of waiting was this? What would they actually *do* during these periods of purported "downtime?" The practices that I saw were similar to those written about in an edited volume on *Care in Practice: On Tinkering in Clinics, Homes and Farms*: "Rather than requiring impartial judgements and firm decisions, they demand attuned attentiveness and adaptive tinkering" (Mol et al. 2010; 15). These were learned qualities which, in some cases, had to be maintained for over a decade without ever finding a truffle and with few signs that a farmer is on the right track. This is what I call engaged waiting.

Engaged Waiting

Engaged waiting does not always involve physical work, but it does require a consistent presence in the orchard. Building on Eric Hirsch's (1995) insistence that landscape is a cultural process, the skill that emerges from engaged waiting is one in which the landscape and the dweller on that land grow and change together; the two influence one another in an iterative fashion. This is not unlike how Cassidy and Mullin (2007) describe the domestication of individual organisms: not as a situation in which *domesticator* dominates *domesticatee*, but as the co-evolution of both. As engaged waiting takes place, landscape and farmer evolve together. In this way, Tim Ingold argues that understanding the nature of skill requires more than identifying bodies in certain landscapes and then "peeling back the layers of representations." Rather, skill is embedded within the landscape itself, which includes soil layers, mycorrhizal connections, trees, and farmers (Ingold 1993). Ingold uses the term *taskscape* to show that this process can only be understood as one that occurs across time: it is the changes that continually occur—across mineral, animal, plant, and fungi—that make up taskscapes. There can be no static understanding of what goes into truffle farming, or makes melanosporum grow. As Daniel Nicholson and John Dupré (2018) say about life in general, "everything flows."

Engaged waiting requires a certain amount of set-up. The mycorrhizal "taskscapes" (Ingold 1993) that form as humans co-learn and co-evolve with soil and trees[76] requires the creation of a *truffle zone* that is appropriate to melanosporum. This involves choosing the right

---

[76] For more on learning with the land, see also Keith Basso (1996).

swath of land, prepping the soil, choosing trees species and planting patterns, establishing a water source and irrigation system, among many other variables.

All of this work indicates how misleading is the notion that truffle farming is hands-off or merely about waiting. Paradoxically, perhaps, it is a crop that requires a high amount of technicality (specific growth requirements) while it also involves an ability to deal with indeterminacy. A lot of work goes into creating spaces that cater to the needs of this Mediterranean fungus, but once needs are met, the job of a truffle farmer is equally about observing the orchard as it is about physically engaging with tree and soil.

PART II: The Biology Behind Engaged Waiting

Truffle Zones

As what biologists call a "pioneer" species (Ricklefs 2015) that thrives in disturbed environments, melanosporum grew abundantly in nineteenth-century France. The Golden Age of truffle production, which lasted roughly a century, beginning in the early nineteenth century, was an opportune period in which Southern France was littered with landscapes of young, open oak forests on well-draining calcareous soils. These are precisely the parameters included in truffle farming manuals and even popular books on truffles in general (Hall et al. 2007; Nowak 2015). In many cases, it merely took a guiding hand to have a highly productive truffle orchard. In postwar France, as landscapes of open oak forests became less common, they had to be created.[77]

---

[77] Once other mycorrhizal fungi took the upper hand across much of France's former truffle lands, they came to dominate in a way that melanosporum formerly had (into the second decade of the twentieth century). There is an advantage that occurs when the fungus becomes plentiful across a wide geography—the spores in question become widespread, waiting to germinate. This certainly contributed to the ease with which melanosporum grew during the Golden Age.

For this reason, truffle farming technician Pierre Sourzat (2017) recommends that prospective growers in the South of France create truffle "bastions." This involves the digging of trenches around the orchard, and even cutting back any forest that may surround the orchard (or not planting next to forested land). Trenching cuts the roots of surrounding vegetation, which harbors fungi that may outcompete melanosporum. This threat is greatest in areas where melanosporum grows naturally, where species such as *Tuber brumale* have evolved to outcompete melanosporum, when the conditions are right (Sourzat 2008). Ironically, it can be harder to grow melanosporum where it has historically grown on its own.

In Oregon, the metaphor of a zone makes more sense that Sourzat's bastions. I take truffle zones to be spaces with boundaries that keep threats out but are also permeabile to the surrounding environment. The metaphor also works well to capture the variability and indeterminacy of truffle farming. It allows for all that is unknown in what melanosporum wants or can handle, while also pointing to what *is* known.

In the Willamette Valley, adjusting soil structure and soil pH are the principal tasks in creating a truffle zone. Melanosporum requires a pH of at least 7.5, and preferably 8 or higher. Raising the pH of the Willamette Valley's acidic soils (acidity rising as a soil dips below a pH of 7) requires a massive amount of lime, upwards of dozens of tons per acre before planting the trees, followed by subsequent applications as the orchard matures. For a ten- to twenty-acre orchard, this takes the form of multiple rounds of sixteen-wheeled trucks dumping entire loads of crushed dolomite or limestone rock. There is a silver lining to such intense liming of the soil. The drastic alteration in soil pH prevents the fungal communities that have evolved to live in Oregon's largely acidic soils from competing with melanosporum.[78]

---

[78] The creation of these alkaline zones, however, also invites other European fungi that are well adapted to live in soils with a high pH. This includes truffle-producing fungal species such as *Tuber brumale* and *T. indicum*, species

In comparison to melanosporum's natural habitat, Willamette Valley soils tend to be heavy and have high water tables. Achieving light (friable) and well-draining soils may begin with the extreme measures of subsoiling or even adding crushed rock to one's soil (a practice that can also increase the pH). Such heavy soils also require routine tilling at superficial depths—merely "scratching" an inch or two into the soil, as one farmer put it. This requires special equipment such as a fine-toothed harrow.

Finally, the trees can be planted and irrigation system installed. A source of water during Oregon's dry summers is critical. Deer fencing may need to go around the entire orchard, or tubes installed around individual trees may be needed for protection from animals and heavy machinery. The pattern and density of planting is done to maximize the sun that hits the orchard floor (mimicking the open oak forests of France's Golden Age of truffle production). Once the trees have grown, particular and often meticulous methods of tree pruning ensure that enough sun continues to come into contact with the soil surface.[79]

Only after the appropriate truffle zone is in place can the process of engaged waiting begin. These extended periods of observing (attuning senses to new mycorrhizal ecologies) and tinkering (lightly tuning these ecologies, when possible and desirable) that I argue are constitutive of truffle farming are linked to a set of unique biological features that distinguish the farming of mycorrhizal fruiting bodies (either truffles or above-ground mushrooms) from any other sort of crop. The first is a period of vegetative growth that can last over a decade; here,

---

that European truffle farmers call "contaminates." There is already evidence that *Tuber* species have unintentionally made their way to North America, via the forestry and nursery industries (see Healy 2016). This could one day be a serious problem for North America's truffle industry. Such widespread "contamination" has already plagued New Zealand's melanosporum orchards (Guerin-Laguette 2010).

[79] A truffle orchard with hazelnut trees stands in stark contrast to a hazelnut orchard managed to farm nuts. Unlike the orchards managed to nurture melanosporum through heavy tree pruning and wide spacing that keeps the orchard open, mature nut-producing hazelnut orchards are dark places with a closed canopy. That said, exceptions are the norm in truffle farming: Long, for example, has managed to produce melanosporum in a hazelnut tree orchard with a (mostly) closed canopy.

management can be lax. The second concerns a period of roughly eight months during which truffles develop; here, management must be meticulous.

Vegetative Growth

After the planning and installation of an orchard, a truffle grower faces an extended period in which the melanosporum and the tree root system (including an array of indeterminate other factors) must develop. This is a phase of underground vegetative growth of the fungus. It consists of fungal sheaths that coat root tips—upwards of eighty percent of the root system, as can be seen in young trees in nurseries. These fungal coatings serve as the point of exchange between fungus and tree. They connect with "extraradical" mycelium that departs from the root structure to extend into fine crevices of the soil matrix in search of minerals to transport back to roots (Smith and Read 2008). In rare cases, this vegetative growth will occur for a mere three years before melanosporum can enter its sexual life cycle and produce fruiting bodies (truffles). More frequently, this vegetative phase that is the precursor to any truffle growth takes the better part of a decade.[80]

Melanosporum's ability to survive for decades without bearing any fruit (i.e. producing truffles) is unlike agricultural crops that follow annual or biannual reproductive cycles. Depending on how a farmer adjusts to this biology, it can either be a benefit or a downfall to the successful maintenance of a truffle orchard. On the one hand, it gives farmers such as Long the wiggle room to focus on other crops (or non-farming projects) and then direct their attention to the truffle orchard when they are willing or able. On the other hand, it is a temptation to *not* keep

---

[80] Truffle orchards also have a third phase, which deals with aging trees and when to replace them or take other drastic actions. This typically concerns orchards over 25 years of age, which do not yet exist in Oregon. I will not discuss the point here.

tabs on the orchard; instead of an opening that makes engaged waiting possible, it is a window that can invite orchard neglect. This, in turn, makes a farmer less familiar with the continual changes in a truffle orchard and more likely to miss early warning signs that indicate blight or less severe issues that need immediate attention. For Long, whose hazelnut trees are not resistant to Eastern filbert blight, this takes the form of pruning infected branches; it also involves adjusting the irrigation system when ground vegetation indicates over- or underwatering.

As became the norm in the truffle industry around the turn of the twentieth century, prospective and new growers took this flexibility in a truffle's growth to be a green light to skip many of the mundane tasks or observations that more successful growers tend to view as critical to truffle farming. Some growers told me about rarely spending time in their orchards during the first few years. After evidence that the seedlings survived the shock of transplanting and exposure to the new environment, they waited out the subsequent years rarely doing anything among the trees. As I learned while visiting truffle farms (in France, Italy, and the Pacific Northwest) a grower could neglect soil and trees for over a decade (in some cases literally do nothing; in other cases maybe mowing ground cover once a year) and still have plenty of melanosporum coating tree roots. This is the biological feature that has given way to a perception that truffle farming is easy and relatively hands-off. However, I noticed that those growers who pay minimal attention to their orchard (and conduct minimal labor) tend to have mature orchards—upwards of fifteen years old—in which no truffle has been found.[81] I heard insiders to Oregon's truffle industry speak of such people as "non-serious growers." They tend to be retirees with expendable income who like the idea of having truffle trees in their backyard, and are often

---

[81] I must note a caveat: when orchard management is neglected it is also common for harvesting to be neglected. This means that dogs are rarely brought on the land and it leaves open the possibility that truffles did grow but were never unearthed by human-dog teams.

nonchalant about the trees eventually producing or not. This is an issue that expands out of Oregon to any location with truffle orchards: non-serious growers are blamed for the global phenomenon of the past few decades in which millions of truffle trees have been planted with few truffles to show for it.

Across France and Oregon, I spoke with roughly a dozen landowners who would fall neatly into the category of "non-serious farmer." They were all retired from a successful career (typically non-agricultural) and had planted between five and twenty acres of truffle trees. They had orchards of between ten and twenty years old and none had found more than a handful of truffles, if any. When I asked what they might have done differently (if they would have done anything differently), almost all lamented that they did not take orchard management seriously.[82] Most went on to explain that they had bought trees with the expectation that orchard management would be minimal. They blamed those at the nurseries where they had bought the trees for this misconception. Two landowners said that nursery owners tend to "oversell" truffle trees. With this comment, the landowners meant that truffle trees had been sold with unrealistic expectations for what it takes to produce truffles, not to mention the likelihood of producing a *salable* crop of high-quality truffles.[83] Nursery owners are certainly under pressure to sell the saplings that they so carefully inoculated with melanosporum. Creating truffle trees is not cheap. Especially since expensive truffles are the principal input for the procedure. Moreover, as the trees age beyond two years, valuable real estate at nurseries becomes an issue. Not only do they

---

[82] Some of these comments were made with more acceptance than regret. With the benefit of hindsight, some spoke as if they had known all along that the trees would never produce truffles. Some blame the placement of their orchard on the lack of production (poor soil, sun exposure, etc.) more than a failure of orchard management.

[83] High-quality truffles can refer to ripeness (indicated by a powerful aroma and jet-black interior with white veins). It also refers to a lack of insect damage (or damage caused by dog claws and human tools during harvesting). The shape and size of the truffle plays a factor as well, especially as some chefs like to present the truffle to clients and shave the fungus on dishes in the restaurant dining room.

take up space where the new batch of trees need to go, the older trees are increasingly susceptible to contaminants or defects such as "J-roots."[84]

Even growers who had expected truffle farming to be hard work and filled with unexpected setbacks told me about nursery employees who described truffle farming as predictable, and, compared to other crops, as requiring minimal labor. A look at truffle tree nursery websites confirm this tendency. A few nursery websites even include precise calculations on the exact hours, per month or season, needed for orchard maintenance. Such numbers do not account for the procedure of engaged waiting: they gloss over the continual stream of unexpected tasks, the last-minute fixes and factors that cannot be overcome and so set back production—all part of an attentiveness that I found to the hallmark of successful truffle growers. As a French truffle technician told me, whenever he attends presentations that include graphs of truffle harvests and profits that follow neat upward curves he immediately discounts the speaker as either someone intent on wooing investors, or as someone who lacks any first-hand experience on a truffle farm.

The Fruiting Cycle

This resilience, or temporal flexibility, of melanosporum (so long as an appropriate truffle zone is maintained) is counterbalanced by a biological feature that is delicate and easily stymied: the truffle's sexual life cycle. The fruiting bodies of melanosporum are unlike most other mushroom-producing species of fungi. Whereas most mushrooms develop in a matter of weeks or days, melanosporum truffles begin growing in April or May and continue their development all the way into November or December. Truffle growth must continue uninterrupted throughout this

---

[84] J-roots occur when roots grow in confined spaces; it prevents proper growth once the trees are outplanted.

period. This requires maintaining specific conditions such as soil that is not compacted or disturbed by machinery (or even a heavy footprint) and not allowing the nascent truffles to go longer than a fourteen-day period without water. If these conditions are not met and the growing truffles die, a new truffle will not form again until the following April or May.

Truffle foragers and farmers have known about these requirements for centuries. Common truffle knowledge recited across the South of France says that extended droughts in the summer lead to no truffles that winter. In places with summers that are increasingly dry and ever hotter, irrigation systems that alleviate the risk of drought are becoming commonplace on truffle orchards.[85] However, questions remain on how much and how frequently to water (so as to encourage the growth of melanosporum and not other fungi) and which physical characteristics of soil are optimal for increasing truffle quantity and shape.[86] Again, while researchers know the general parameters that make up a zone for truffle production (the vegetative growth of the fungus), this zone remains opaque. Indeterminacies only increase when it comes to how truffles form. The challenge of truffle farming lies less in keeping the fungus alive in the orchard over the decades than in being attentive during the seasonal months-long maturation of truffles. The fact of truffles growing under- rather than aboveground makes truffle farming an especially delicate and nuanced form of agriculture, one that leads to differing approaches to how best to farm truffles.[87]

---

[85] Such climatic changes are common in both France and the Pacific Northwest (Thomas and Büntgen 2019).

[86] The shape and quantity of truffles can be a tradeoff. Chefs prefer well-rounded truffles to shave on pasta dishes in front of customers in the dining room. But soils with rocks that tend to distort perfect spheres may lead to a greater quantity of truffles in the orchard.

[87] This delicacy of a truffle's fruit extends to its harvest, distribution, and consumption. A dog's claw can easily break a truffle's skin (peridium) and drastically reduce the truffle's economic value; a fresh truffle remains at peak ripeness for a matter of days (maybe a week); preserving or freezing a truffle robs the ingredient of most of its olfactory qualities; and, finally, although a truffle's aroma is pungent in some ways, it is delicate in others—this delicacy requires a well-trained chef to prepare it.

Part III: The Frugal Farmer

Local Knowledge Exchanges

What I have described through the concept of engaged waiting overlaps with a farming archetype that Peggy Barlett (1993), in her study of a farming community in Georgia that weathered the farm crisis, refers to as a farming "management style" of "frugality." Frugality is certainly a key part of Long's conditions for how to farm "sustainably." Long had enough capital from a career as a veterinarian to invest in land outside of Corvallis and to set up various farming projects. Regardless of how much expendable capital he had after setting up the truffle orchard, he told me about his insistence to not indiscriminately "throw money at the orchard." Long is not only attracted to what he called crops that are "new and unusual" for a region. A large part of the attraction for Long is how to grow truffles frugally. This is central to his definition of "sustainable" farming. It is an ethic that he says was instilled in him as he was growing up on a working farm in Kansas. "By sustainable, I mean economically responsible." To Long, this does not mean spending at one's financial limit, but beginning as economically as possible regarding farm labor, machinery, and inputs. On a few occasions, he described how this personal fiscal responsibility mixes with an ethical responsibility to find a crop that benefits the local economy. Only after such explanations would he note the need to steward the soil, almost as if this point was too obvious to be spoken.

Long's actions back up his words. While deciding if melanosporum was the right crop, he called regional chefs to ensure that they wanted and would buy the product. This was more important than ensuring that he could find brokers who would purchase or link him with buyers who would take the product to distant markets. I saw Long's strong commitment to local food systems in action when his go-to regional buyers had all the truffles they could use. Instead of taking the easier route of contacting a broker who would sell to the East Coast or even abroad, he went through the trouble of driving thirty or forty minutes to solicit chefs at high-end restaurants, in towns within what Philip Ackerman-Leist (2013) would call his foodshed.

On the orchard, Long's frugality—his sense of sustainability—concerns what inputs and machinery he is willing to buy and to what extent he is willing to outsource labor and knowledge. Long takes pride in not buying high-end or many pieces of farm machinery. He weighed the pros and cons of paying for an out-of-town truffle-orchard consultant (at the time no local consultants were available for hire). He decided that the high price of a consultant—in particular one that lacks knowledge of the local environment—is not worth the expense. He instead has pulled from the expertise of a diverse set of people in the region, and has come to insist on turning to local knowledge. For instance, he turns to mycologists at OSU to learn about the mycorrhizal symbiosis;[88] he works with regional farm suppliers who rent out subsoiling equipment or sell pest control products; he speaks with experienced filbert growers in the area for tips on maintaining the health of hazelnut trees. Although melanosporum is now cultivated around the globe, he does not trust the advice of someone who is not familiar with the local conditions. As Long told me about his endless and ever-rotating experiments, as well as the people with whom he speaks about agrarian practices and products, I came to see him as a sponge that can soak up knowledge from any sort of person or context, and convert it to his needs. This is a necessity, for, unlike established crops in the area, there is no *one* "expert" to

---

[88] Long was encouraged to grow truffles because of the resource of nearby mycologists. In the end, however, he has not used this form of expertise as much as a mixture of other sources. In this way, we have a reversal from Chapter 1 in which NATS members were reliant on James Trappe and other professionals in order to learn how to truffle in a manner that would be scientifically relevant (and thus achieve scientific credit). With truffle farming (as opposed to taxonomy), researchers turn to the knowledge of farmers more so than the reverse.

whom he can turn; there is no center of a regional community of practice which he can aspire to enter. When he first thought about farming truffles, Long identified the lack of any center of local expertise in melanosporum farming. Long turned this lack of any well-defined expertise on truffle farming in Oregon into a source of personal satisfaction— which comes from tinkering with the knowledge he has gathered from disparate sources and doing so in a way that will give back to the local food system and help others in Oregon farm truffles. He reaps the rewards not of creating generalizable best practices, but of figuring out a way to grow truffles within the constraints of his own soil, water availability, personal ideas about sustainability, and labor limitations. He told me with measured excitement that when growing truffles in Oregon "there is no recipe. You have to learn how to cook." This challenge of learning how to cook, with utterly new (agrarian) ingredients, is precisely what drew Long (and the majority of truffle farmers whom I met) to truffle farming in the first place. Long's inquisitiveness is infectious. Every time that I visited his orchard, I was subjected to a quiz of one sort or another: What are the early warning signs of Eastern filbert blight? What is the best material to cover breached truffles? How late in the season can one till the orchard floor? To answer some of these questions, I put him in contact with growers and consultants in France. He has since gone to France to visit these consultants, and "observe" truffle orchards. "You never know what you'll learn," or, "how you might apply" the knowledge, he told me.

Long places equal emphasis on sharing knowledge as he does soaking it up. Part of Long's agrarian ethic is to share the knowledge that he gathers. He has ended up being a sort of trading circuit for truffle production knowledge in Oregon. He gives talks to groups such as the Corvallis-based North American Truffling Society (NATS) and the Growers' Forum at the Oregon Truffle Festival (OTF). The Growers' Forum at the OTF often includes a visit to his orchard. He told me that when giving these talks, he typically learns just as much as he teaches—this attests to his ability to always learn from a situation. In these ways, he works to circulate the knowledge that he has acquired and that he has built up on his own. But he is always careful to present his findings as what has worked for him, on his particular swath of land. He is aware of the danger of generalizing prescriptions in truffle farming, and respects the need for growers to figure out what production methods work best for themselves on their own land (and that this will entail some failed experiments).

In exchanging information on farming practices with others, Long has come to realize how much of his knowledge is tacit (see Polanyi 2009). On one occasion, when speaking with Long, I used the word "tacit" in reference to his knowledge practices. He stopped me, asking what I meant. He was not familiar with the concept, but understood my explanation that tacit knowledge referred to a practical know-how of which the holder is not explicitly aware, or cannot put into words. Beyond understanding the concept, he felt it as a reality. As an example, he expressed his surprise at the difficulty of what he thought would be a simple task: fulfilling a request from an inquisitive grower to write down, on a month-by-month basis, what he does in the orchard.

During my fieldwork period, Long indeed received more requests from (sometimes prospective) truffle farmers for tips on orchard management. This leads to the questions: What do these inquisitive growers hope to get out of truffle farming? Have they taken up the pursuit for reasons similar to Long's? Long insists that truffle farming is a hobby for him, but he also explained to me that "he picks hobbies that will pay for themselves, and then some." Long would not have gotten into truffle farming had he not thought he would make money from the pursuit. Although he was direct on this point, he also insisted that money is far from the central reason why he got into truffle farming. Long told me about a more valued form of capital, which is part intellectual satisfaction and part ethical. The latter, Long explained, comes with the prospect of bringing a new crop to Western Oregon; local chefs stand to benefit from locally grown truffles (as does the broader gourmet food industry that thrives in Oregon), and so too do farmers whom Long might embolden to take up truffle farming, and who might find in truffle farming a needed boost in farm revenues.[89] This links up with what Stephan Gudeman (2001) describes as the community "at the base" of any economy or marketplace. As demonstrated by his insistence on exchanging knowledge locally, and selling within his foodshed, Long implicitly understands Gudeman's point. But as Long learns more about truffle farming, and as other successful growers and truffle experts come on the scene, he is aware that fewer of his methods are being replicated by other growers. Long's know-how continues to evolve along with Oregon's melanosporum industry. Long has retained a sense of humility as he and other melanosporum growers across North America are made aware of how little they knew when buying and planting their truffle trees. Long's ample reserves (of economic and psychological capital) enabled the extended periods of experimentation (failures and successes) to be a joyful and not an anxiety-ridden experience.[90]

Leisure Capital

Long does not regret his various delays in production, or management practices that lowered the quality of his truffles. Whatever he may have lost in economic capital, he gained in what we

---

[89] Mirroring reports from nineteenth-century France, I met with a few farmers who already had the farming equipment, irrigation system, labor-time, and unused land needed to start and manage a truffle orchard. For these individuals, trying their hand at truffle farming merely required an investment in the truffle trees themselves (which, depending on the size of the orchard, can cost tens of thousands of dollars).

[90] Only in the last year or two of fieldwork did I hear Long and others speak with any kind of confidence that a North American could turn a profit selling truffles themselves (rather than just agrotourism and truffle "experiences" sold by companies like Airbnb, see more below).

might call leisure capital; that is, the ability to take one's time while experimenting, and to learn through these extended time-frames. Barbara McClintock, later in her life, when speaking to researchers and students at Harvard University, told the group about the kind of knowledge that can only come with extended hours (years even) with one's research subject; she insisted that they "take the time and look" (Keller 1983; 142). Similarly, Isabelle Stengers (2018) advocates a "slow science," one that is necessary for the holistic understandings (which relate to longer time-frames) that McClintock also stressed. Stengers laments that across scientific disciplines extended time frames are losing favor.

In Long's case, these extended time-frames are also a practical manner. Long planted his trees during a time when he was harvesting a few thousand pounds of tomatoes a season, without any hired hands, while also spending an average of twenty hours a week visiting alpaca and llama farms. He knew that this work would slow down in the subsequent years, when he planned to spend more time in the truffle orchard. (Intentional or not, this was also how Long dealt with years of free-floating anxiety: he worked his way through it—although he admits that he became despondent after his trees had been in the ground for eleven years and he had still not found a truffle.)

Long now feels confident that he could have harvested truffles starting in year eight or nine. He pinpoints the factors that prevented earlier production to a slug population that he let get out of control (a problem with many Willamette Valley crops), and not irrigating as much as he should have. He learned about the latter issue after noticing that all of the truffles that he harvested in the first few years came from a strip of land that was next to his vegetable garden. Long realized that these areas received double the irrigation. He quickly upgraded his irrigation system and he has found truffles under an increasing number of trees with each subsequent season.

His next big learning experience involved "breached" truffles. When portions of truffles appear above the soil surface, the truffle is almost certain to experience rot. A certain percentage of breached truffles in a season is unavoidable. Long, however, had a high percentage. It was only after a fair amount of experimentation with using different materials to cover these breached truffles (sand, crushed oyster shells, even plastic containers) that he turned to "subsoiling" (plowing deeply into the soil along the tree rows to break up compact lower layers of soil called hard-pan). He took this extreme measure after realizing that his soils—heavier, with a fairly high clay content—were causing truffles to grow too close to the surface. Breaking apart the compacted soil encouraged truffle growth deeper down. He continues to experiment with annual, less severe forms of tilling.

Leisure capital has enabled Long to carry out experimentation with enjoyment and no economic hardship. But strong financial standing is not enough to make such experimentation enjoyable rather than riddled with anxiety. Leisure capital also involves a *willingness* to go through the trials and tribulations of engaged waiting.

Another kind of truffle farmer now on the rise in Oregon lacks the funding, know-how or simply the desire to deal with the adaptive tinkering of engaged waiting (which includes impromptu and often unprecedented knowledge exchanges off the farm, followed by temporally extended tinkerings on the farm). This group has been emboldened by the rising number of melanosporum orchards that are coming into production, across the globe. Although concentrated in a few locations (southwestern Australia, southeastern Spain), truffle farming now shows a strong trend towards standardized, scaled, and reliable production. This has fueled a group of truffle farmers who are less willing to view engaged waiting (with its extended time frames and experimentation with requisite setbacks) as constitutive of truffle farming. Maybe they rely on truffle farming for a portion of their livelihood, or they have put all of their nest eggs in the truffle basket. For still others, the joy of experimentation comes not from how to produce truffles frugally but how to help create better guidelines for an entire industry of growers in the Pacific Northwest.

PART IV: A Professional Ethic

Prospective Grower: When did you first find truffles?
Grower: First one came two years ago.
Prospective Grower: How old are your trees?
Grower: Fourteen years.
Prospective Grower: What *happened*?

This conversation occurred during breakfast at the 2018 Oregon Truffle Festival. Only after asking “What happened?” did the prospective grower realize how aggressive the question sounded. With a softer and more gentle tone, this grower-to-be asked, “Who do you work with?” This question referenced truffle orchard consultants, which the grower with fourteen-year-old trees has never used. That a grower just getting into truffle farming was shocked about a period of over ten years passing before any truffles being found indicates just how much has changed in truffle farming, even since I began fieldwork. When conducting preliminary fieldwork in 2014 and 2015, such a waiting period was to be expected.

João Biehl and Peter Locke (2017) describe the inescapably “unfinished” quality of fieldwork. The “lifeworlds” of those we befriend and study (with) are changing, in real-time, along with our own lives. Biehl and Locke point out the miniscule slice of time that we are in our informants' lifeworlds—their geographies, thoughts, and social circles. Lives and societies are always already in flux. They are always *continuing on*, and the ethnographer can only be left with fragmented glimpses and snapshots of far greater stories and circumstances.

I was in Oregon during a critical phase of the truffle industry. The first fifteen years of the twenty-first century saw a significant uptick in the planting of truffle trees (since the 1980s), but few truffles had been found.[91] From 2015 to 2018, however, I was present (sometimes physically present with the dogs digging up truffles in the orchard; other times in ongoing conversation with growers) while eight truffle farmers found their first truffles. The 2018/2019 harvest season has brought a new wave of fruitings in California (both on private orchards and small orchards on larger, industrial vineyards).[92] That there are likely over a dozen orchards in North America in which at least a few melanosporum truffles have been found may sound inconsequential. However, compared to the past four decades (the period in which melanosporum farming has been promoted and attempted in North America), the past five years have seen an exponential rise in producing orchards. This is a significant achievement that has emboldened many to join the industry.

An important detail about these newly producing orchards is that they have come into production in a little as five years. And only a few of these farms have taken more than seven years before the first find, as the steady stream of news articles point out, introducing a new expectation and guideline for truffle tree production time-frames. Among growers in North America, finding truffles in an orchard that is over a decade old is hardly newsworthy. For many, it is becoming a sign of a "non-serious grower," that slander that I commonly heard among

---

[91] There were a few cases of success with European truffle species other than *melanosporum*, which are easier to grow yet have lower market values (e.g. *Tuber borchii, Tuber aestivum*). Here I retain a focus on *melanosporum*.

[92] These farms are grouped northeast of the Bay Area. Farms that produce melanosporum, along with other European truffle varieties, now exist in British Columbia, Canada, Idaho, and across Appalachia.

industry insiders. The subject of this slander has shifted. It is no longer reserved for those who buy a few truffle trees to plant in their backyard, with little expectation of finding truffles—as one nursery owner put it, those who see truffle production as an afterthought and are happy to merely have "trees with a story" that they can share with friends.[93] This insult has shifted from a grower who never produces to one who produces too late. Waiting over a decade for one's first truffle has become *delayed* production, a sign that the grower "went wrong" (as quoted above) somewhere along the way. I heard this critique strongly spelled out by a handful of growers who have installed truffle orchards in the last few years. I will now discuss Miller, a character (and orchard) that is a composite of these voices.[94] I consider Miller as embodying a professional ethic that I argue is on the rise in Oregon, and which seeks to reconfigure what constitutes a "good" or "skilled" truffle farmer.

Miller's Professionalism

Miller has worked as an engineer for water infrastructure projects for decades (most in the truffle farming group I refer to here have backgrounds in engineering or the biological sciences, training that emboldens them to take on the highly technical project that is truffle farming). He continued to do so even when he bought a dozen-acre parcel of land with a ranch house, estimating that the location would work well as a melanosporum orchard. If all goes according to plan, Miller will

---

[93] This story—of having trees whose roots are part of a richly mysterious symbiosis, matched with the potential of randomly finding one of the most coveted foods on Earth—can proudly be told in Facebook posts and at backyard parties.

[94] Miller's orchard and management practices are also a composite of those of of group of farmers. This composite character necessitates a note on the gender distribution of truffle farmers: aside from a few isolated cases, women are involved to the extent that an orchard is managed by a couple, or in some cases by the entire nuclear family. Even then, men tend to take the lead in orchard management. In one case I saw a rather equal division of labor (between the woman who had experience as a biologist and the man who had experience as an engineer). The other common division of labor has women in charge of truffle dog training and truffle harvesting. Indeed, in the industry of truffle dog training, and any other truffle dog services, women dominate.

be able to quit his day job and focus solely on his truffle trees, what he has called "my boat," in a number of years. I was confused when Miller first made this reference to a watery past-time. It was a beautiful fall day in Western Oregon and we were walking from the orchard, back to his house for a beer. He turned and gestured to the expensive trees, nestled in front of a beautiful Oregonian mountain backdrop. "This is my boat. At this point in my life... it is how I have chosen to spend my money." I sensed a slight insecurity in his words, or perhaps envy for those nearing retirement age who have invested their surplus money from an economically fruitful career in an expensive boat—a commodity imbued with the imagery of leisure that does require upkeep, but has a more certain resale value than a truffle orchard (this is the "leisure consumption" that Thorstein Veblen wrote about in 1899). Miller is not like those truffle farmers who would make such a comment and then explain how the investment will pay off far in the future, likely benefiting their progeny rather than themselves. Miller does not have any children and he is committed to profiting from his investment sooner than it would take for a youngster to come of age. This is where his professional ethic comes into play.

Miller's professional ethic began with the legwork he put into choosing the location for his truffle orchard. In searching for a piece of land on which to grow truffles, and not trying to make land already owned fit the peculiar form of farming, Miller is part of a growing trend in Oregon. Miller searched many properties in Western Oregon, with an eye for potential issues such as water access, soil type, and sun exposure. Miller tries to differentiate himself from others in the industry who have more than enough savings to set up and maintain their orchard. In saying that he would have liked to buy a bigger piece of land and grow more trees, but that he did not have the savings, he at once reinforces a perception of truffle farmers as affluent and positions himself in a lower socio-economic class. This feeds into his telling me that *all* of his retirement funds went into the orchard. Despite such financial limitations, he insists on farming truffles "right," which to Miller means taking whatever measure necessary, within the limits of his capacity, to grow truffles as quickly as possible.

Miller articulated truffle farming to me as a leisurely pursuit. But there is a contradiction in this statement. More of his words and actions speak to the *need* to skip over the rewarding (if hard won) tinkering and experimentation done by Long. He frequently stressed that he does not have the capital (time and money) to grow truffles following what I call engaged waiting. Miller has no regret for this fact. His gratification does not come from learning how to best grow truffles via trial and error, and by pulling from a hodge-podge of incomplete knowledge sources. He admits that ten years ago this tactic may have been necessary. Today, however, the knowledge is there—you just have to know who to ask, and be willing to look abroad.

Still, when he first planted his trees, Miller did not know who to ask for orchard management. At the time, nursery owners were not yet willing to offer orchard consulting services (they are now, another trend that occurred during my fieldwork period, see below). Miller laments the ignorance that he had when he installed his orchard. "I made many mistakes," he told me, which he could have "easily prevented." After this rocky start, he then found a truffle orchard consultant from a well-known truffle producing region. Miller narrates his hiring of the consultant as a move from ignorance to knowledge. Disingenuous or not, I heard him say to a group of prospective farmers at a truffle festival in Washington: "I went into this blind…don't do the same." This consultant has since become well known in Oregon. He lives in Australia and makes an annual (or seldom bi-annual) trip to Oregon to advise a number of truffle farmers. During these visits he gives his clients more information than they could ever hope to absorb. This is how Miller described it to me. All of this knowledge (aside from what the consultant has said himself, publicly) is proprietary. Non-disclosure agreements are signed by everyone who pays for the knowledge. When on Miller's farm, when discussing his practices, Miller seemed to take pride in what he could not tell me. These were purchased secrets that helped make him a skilled farmer. Miller respects Long's hard-earned ability and ingenuity in farming truffles; however, he also makes a point to tell me that following his consultant's advice, he manages his land differently (the truffle farming community is small; the two know each other). Providing an example, Miller said, "It's tidy. We take care to keep the [orchard] floor clean." It's true. Miller takes the time to rake or blow leaves out of the orchard; he regularly mows the grass in the tree rows, and keeps all ground cover short. Long does not.

Not all of Miller's management methods were directed by his consultant. He does not rely on his consultant to the extent of some growers I met. Like Long, he reads scientific papers and exchanges ideas with regional growers. In fact, his desire to experiment with some growing methods that were not advised by his consultant is a point of tension in the relationship. Other growers with whom I met refused to work with this consultant, after having learned that they would *only* be able to follow those methods the consultant advised, regardless if they thought otherwise. This raises the important question of what kind of knowledge is held by a consultant from another hemisphere who only visits the orchard in question once a year—even if this person has four decades experience of working with truffles. Put differently, to what extent are orchard management techniques unique to particular farms, or regions? To what extent are they generalizable? A lot is at stake in each of these questions. The ability to standardize orchard management practices—the creation of "best practice" guidelines for climates, soilscapes and farming types across the globe—would make truffle farming more like other forms of industrial agriculture. This is precisely the goal for many truffle orchard consultants and other truffle farming entrepreneurs: proprietary methods or industry secrets for such standardized growing methods is a recipe for riches from truffle farming. This is money made *not* through the sales of truffles, but through the sales of helping others farm truffles. However such standardization would take away the joy that many truffle farmers find in the pursuit. Truffle farming would not contain the same kind of adaptive tinkering enjoyed (for the most part) by growers like Long. This is akin to what Anna Tsing (2000) has called "scale making." Tsing critiques the allure of narratives of globalization, which speak glibly about practices and "flows" of information and materials that erase culture and space as they move and come to dominate around the world. Standardization, or scale-making never happens so smoothly, products and practices never look or act quite the same in different times and places, and truffle farming is no exception to this point. Similarly, Long believes that truffle farming practice necessarily contains regional and locally specific knowledge.[95] Aside from the cost and his belief that such knowledge should not be proprietary, this is why he declines to work with star consultants who live on and are familiar with lands that are far away.

Miller will be the first to say that growers who tend the orchard throughout the year, even if they have the best consultant, must also possess a certain baseline of agronomic or agrarian knowledge, and have a curiosity (humility) and work ethic that it takes to fill gaps in one's knowledge. I found that across the board (whether a grower subscribes to practices of engaged waiting or holds more of a professional ethic) successful growers balance an entrenched expertise with the openness and humility that it takes to continually learn, via personal experimentation. Much of the division between the qualities of what constitutes a skilled farmer

---

[95] "Local" is a particularly slippery term, as Emily Yates-Doerr (2017) has demonstrated. For Long, it is as specific as quadrants of his orchard.

comes down to the extent to which a grower is willing to (or wants to) outsource skill—whether this outsourcing goes to hired labor, consultants or even high-tech machinery.

Following Lave and Wenger's framework of legitimate peripheral learning, which suggests that there is a core group of experts one can strive to emulate, we can ask, where is the center of expertise in Oregon's truffle farming community? Clearly consultants strive to position themselves as this center. (One consultant, who told me that truffle farmers and farmer associations are "the blind leading the blind" was clearly doing this work). But what if a farmer does not use a consultant? And what if there are no other truffle farms in a prospective growers area? This has been the situation confronted by Long, and it has morphed Lave and Wenger's diagram of concentric circles (with expertise at the center) into a vast and complex epistemic topography that one must traverse in the search of truffle farming knowledge.

How to Judge a Skilled or Successful Truffle Farmer?

Miller found his first truffle after his trees had been in the ground for six years. Like Long's orchard, Miller's production has since increased with each subsequent year. Still, Long produces many times the magnitude of Miller. With a friendly but competitive air, Miller is quick to point out not just how much older is Long's orchard, but also the large quantity of truffles Long loses to rot (breached truffles, and what he attributes to the Long's failure to clean the orchard floor, litter that makes great habitat for truffle-eating insects). Long is okay with these losses whereas Miller finds them unacceptable. This is where Miller's professional ethic shows. This ethic brings a shift in what constitutes success; it again raises the question of what one hopes to get out of the act of truffle farming.

A certain quality of the professional ethic works against the frugality that comes with Long's definition of sustainability. Miller points to his many pieces of farm machinery (harrows, plows, tractors) as evidence that he is a serious grower, and as evidence of his farming skills. He speaks similarly of a fertilizer product that he and a handful of growers in Oregon use.[96] The skill set that Long values, his "sustainable," involves learning how to *not* use such resources (inputs and other products, machinery or labor). This is where the frugal farmer critiques those who are quick to "throw money at" their orchard. Paying for a consultant to tell you how to farm truffles is especially contentious: one the one hand this is a missed opportunity to learn from those who have already been through the trial and error; on the other hand, this is a prime area where one can cut back on resources.

Like Long, Miller takes pleasure in sharing his orchard-management techniques with others (to the extent permitted by the non-disclosure agreement that he signed with his consultant). Unlike Long, Miller's sharing of knowledge can at times come off as advocacy, part of an effort to build new standards in melanosporum production in Oregon. He proudly calls himself an "early adopter" in the industry. He balances the satisfaction that comes with helping set up a future industry, with the more leisurely (and personal) joy that comes from working on "his boat." Watching him interact with other growers, I have seen Miller focus on setting standards ("best practices") in the industry. Aside from promoting the use of consultants and products that may increase production, he now works to set grading standards of truffles, as well as distribution channels. In this way, Miller seeks to be a trendsetter and is attracted to the

---

[96] The product called "truffle boost" is made by an Australian company. The product itself is not necessarily unsustainable (it is purportedly not derived from chemical materials, but natural ones such as kelp). But it does accumulate with other inputs and practices to make some styles of truffle farming resource intensive. Additionally, the use of truffle boost is a divisive topic among Oregon truffle growers: some, like Miller, swear by it; others question its efficacy and note that studies that demonstrate its efficacy come from those who produce and sell the product.

challenge of making melanosporum a standardized crop in Western Oregon. Long, on the other hand, is happy to produce what he called "new and unusual" crops; as founding NATS member Frank Evans described truffle foraging in the 1980s, Long is attracted to the "delights of the esoteric" (only now we are talking about experimentally farming truffles, unlike foraging for truffles as described in Chapter 1).

Creating a Niche, Apart from the "Big Landowners"

Both Long and Miller follow self-fulfilling ways of working with melanosporum: they are guided by two different motives to farm truffles. They also uphold different visions for Oregon's truffle industry. In Miller's opinion, undirected experimentation, without a clear center of expertise (as Lave and Wenger would have it), or without a clear end in view, will undercut the development of a regional industry. The reputation of truffle farming in Oregon would be in tatters; production would be inconsistent and small and only advance slowly. The fear here, as Miller has voiced it on a few occasions, are the "big landowners" from California, whom, he is confident, will soon invest in melanosporum farming.[97] Nodding to Oregon's wine industry, Miller (along with other Oregon boosters) argues that Oregon growers must differentiate themselves from the imminent, industrial-sized threat from California. The way to do this is to market Oregon-grown melanosporum as being a product of higher quality, and hence of higher economic value.

Miller seeks to promote a certain ecology of production for melanosporum farming, one that will bring greater economic value to Oregon-grown truffles and truffle-producing landscapes. This begins with deep histories in which an ingredient alleged to have aphrodisiac

---

[97] Considering the recent growing investment in truffle production in California, Miller's, spoken in 2016, have proven prescient.

qualities and promoted by famed food essayists (Brillat-Savarin 1834), kings and queens and countless celebrity chefs (see Rebière 1967) is grown in Western Oregon, a place of bucolic agricultural bounty (see Robbins 1997). Greater economic value then comes with the cultural perception of truffles as wild and "natural," even if farmed. Bucolic green symbolism is layered with notions of a working landscape created through admirable agrarian craft (see Paxson 2013)—a sort of labor that now attracts second-career farmers emboldened by experience as an engineering or in a biological science; others may simply want to experience the landscapes, and the truffles on a weekend or afternoon getaway.

The most alluring component of melanosporum's ecology of production may come from narratives that speak of the impossibility of managing the mycorrhizal fungi (see Matsutake Worlds Research Group 2009). These narratives compound with a mystique already possessed by truffles, and contribute to the popularization of a rapidly growing science. Mycorrhizal science is now sensationalized (via rather extreme cases of anthropomorphism) by popular writers (Wohlleben 2016) who translate research which itself uses metaphors of "mother trees" who give to young or weak trees (Simard 1990) and mitigated resource "inequities" (Whiteside et al. 2019) among communities of plants and microbes—relations that even enabled plants to evolve onto land.[98]

Narratives that have the mycorrhizal symbiosis as unruly are a boon to Miller and his promotion of his truffle orchard— they make it all the more amazing when Miller explains that he has overcome formidable hurdles to be a first of his kind in succeeding to farm melanosporum

---

[98] Talks by truffle orchard consultants and related promotional material often include impressive descriptions on the mycorrhizal symbiosis writ large, namely that the symbiosis encompasses 80% of plants on Earth and has been around for 450 million years. On a few occasions Miller has mentioned such an interest in evolutionary science. I have also heard him wax poetically on how much is unknown about the mycorrhizal symbiosis, and, as he said "how much will never be known." Miller is very aware that much of the draw, the mystique, of truffles comes from the popular perception that they cannot be cultivated.

in Western Oregon. As Miller is banking on, this all is more than enough allure to sell truffles and promote agritourism on his orchard.

Selling an Image of Truffle Production

To Miller it is a given that melanosporum will become a significant crop, and a profitable industry. The question is *where* this will happen, and when. Regions in North America now vie (and also collaborate) to become the location in North America best known for the production of European truffles. Most of these regions have their own truffle festivals, such as the San Francisco Bay Area, British Columbia, and central Appalachia, as well as Oregon. Growers like Miller, who did not start a truffle orchard to leave a nest-egg for their progeny, are working the hardest to shape and build regional truffle industries— for instance, he strives to give public talks on how to farm truffles well, and he pushes for grading standards of truffles (anticipating that truffles will come, and that subpar truffles need to be categorized and separated from "grade A" ones). Miller does not even plan to "retire" on his orchard. He rather speaks of converting the modest house next to the orchard into a bed and breakfast, and then selling the whole package to someone looking to get into agritourism. This plan hinges, however, on his orchard coming into full production. He banks on the fact that a "producing" truffle orchard will sell for top-dollar. With the returns from this potential sale Miller intends to invest in an orchard that is at least twice the size of his current ten acres. The second time around, he can do it "right," and not go through some of the mistakes that he believes has slowed or otherwise made his production less than optimal (as with Long, these issues include fine points of irrigation, pruning and tilling).

I heard from numerous growers such plans to profit by starting orchards only to sell an established orchard for a profit to prospective growers ("turn-key" orchards). As of 2019, one grower already had his truffle farm on the real-estate market. Aside from truffle sales, a more common strategy to profit from one's orchard is agritourism. Truffle agritourism is a lively industry in more established truffle production regions such as France, Italy and Australia—Oregon growers have taken notice. Agritourism may be as involved as building a Bed and Breakfast on the orchard. One grower told me about plans to construct a few yurts, literally between rows of truffle trees. Less involved strategies involve truffled dinners on the orchard. As one grower told me, the truffles do not even need to come from the land. So long as the guests get to walk the orchard with a trained truffle dog (preferably a Lagotto romagnolo, see Chapter 1), they do not actually new to find truffles to be satisfied.[99]

On this topic of promoting one's orchard I noticed a division within the truffle growers with whom I spoke. On the one side are those with no intention of making their orchard public. In some cases they would not even disclose the location of their orchard to me. On the other side were those who actively promote what they see as their truffle business via marketable names for the orchard, business cards, websites, etc. Those who lean in the latter direction intend to carry out some degree of agritourism or other form of community involvement with their truffles or truffle farms.[100] This ranged from selling directly at local food festivals, to hosting ticketed truffled dinners on their farm, to overnight stays.

---

[99] I witnessed such mushroom agritourism in locations such as Yunnan, China and Oaxaca, Mexico. It is true that gourmet adventure seekers do not need to find the foods themselves to feel satisfied. They merely need to be where the food is produced. They are happy to eat mushrooms that someone else has found, even if the mushrooms were found elsewhere.

[100] I do not take these statements to be representative of truffle growers in general, in Oregon or the continent as a whole. My research was not designed for quantitative analysis, and even if my sample size was far greater, growers willing to speak with an anthropologist is a contingent heavily biased toward those interested in building tourism into their truffle orchards, seek to sell their truffles directly to consumers, or who otherwise do not shy away from public engagement. Many other truffle growers whom I have not explicitly written about in this chapter choose to live a private life. They were less willing to speak with me and have no plans to profit from truffle tourism or speak publicly about truffle farming. Many growers in this category I only spoke with once.

To varying degrees, all who openly market their orchards do so in a way that features a romanticized agrarian landscape (as described above), but also a swath of land and a set of practices that are part of a broader effort of regional land stewardship and biodiversity enhancement.

Truffle Farming as Eco-friendly

For French truffle growers, Ever since the aftermath of the French Revolution, truffle farming has been associated with land stewardship. On one level, this is simply due to the planting of trees where forests had been decimated; in nineteenth-century France this qualified truffle farming as an act of patrimony (see Giono 1985). Jumping to today, a co-owner of one of France's largest truffle tree nurseries contrasted the vast amounts of pesticides that are used on grapevines (especially "high yield" varieties used to make spirits or budget wines) with the absence of pesticides or fertilizers used in truffle orchards. As we drove past a small village that was literally surrounded by grapevines he asked me: "do you know the quantities of pesticides they use?" He then called it "foolish" to think that these chemicals do not drift into the village (see Harrison 2011). He now advocates that growers pull out vineyards that surround villages and public parks and replace them with truffle orchards. On one occasion, when I visited a truffle orchard in eastern France, the owner pointed to the array of wildflowers growing on the orchard floor and the diversity of trees used to produce truffles (black pine, two oak species, hazelnut) to indicate the high levels of biodiversity on his truffle orchard—levels far higher than the surrounding fields of wheat and brassicas.

This environmentally friendly image of truffle production has become a key component of the ecology of production now sold by Oregon truffle farmers. The come-visit-our-farm feel relies on an orchard of "human-scale" (Schumacher 1989) that is also bio-diverse and eco-friendly. Miller has told me that what he does has a positive environmental impact. "We're planting trees," he said about truffle farmers in general, suggesting that this, by itself, is a noteworthy (if not philanthropic) contribution to the environmental challenges of the twenty-first century. On another occasion he mentioned how trees sequester carbon. It was when trying to identify some of the many mushrooms that had popped up on his orchard, when he said proudly that his orchard positively affects biodiversity. Such diversity on truffle orchards has been documented in France (Sourzat 2004; Le Tacon 2017). The same cannot be said for orchards in Oregon. This was the opinion of a few mycologists in Oregon, including nearly all of the commercial foragers with whom I spoke, who hunt for culinary truffles found naturally in Oregon.[101] They see the labor and resources as anything but friendly to local environments. The "control" of pests such as burrowing animals, and the often extreme soil work (heavy tilling and application of lime) were most often cited in this regard.

Such critiques notwithstanding, a case can be made for the eco-friendliness or land stewardship qualities of truffle farming. The engaged waiting practiced by Long minimizes some of these critiques—his orchard floor has more plants and he uses fewer inputs and less machinery so as to minimize his carbon footprint. In general, his style of orchard management affords an environmental looseness in which more lifeforms are allowed to thrive (act as they would without a human hand, tractor wheel, or plough tine that manipulates). But I rarely heard Long make claims of environmentally-friendly farming (however we define the category). The increasing paradox among Oregon truffle farmers is that those who boast of eco-friendly practices are also those who advocate that the industry move away from more biodiverse and less

---

[101] Of course these commercial truffle foragers have an economic reason to feel threatened by more truffles for sale in Oregon.

resource-intensive forms of truffle farming. Growers like Miller make a big show of how they steward the land, while they actively seek ways to farm truffles with ever tightening control of the environment (i.e. the flourishing of fewer organisms). This is not to say that greater or more consistent yields of melanosporum require industrial and intensive forms of land use. But this is how boosters of Oregon-grown melanosporum currently frame the industry's growth.

CONCLUSION

In this chapter I have described a style of engagement in early forms of truffle farming in Oregon, a way of farming truffles that has been practiced in France since the early nineteenth century. This is a manner of truffle farming that requires minimal resources and facilitates environmental care— even land restoration—and that can remain flexible to the economic limitations and cultural-ethical values of a farmer. With truffle farming growing in popularity, I have since witnessed the rise of another set of qualities that constitute what it means to be a good and skilled farmer. These skills overlap with and diverge from the leisurely qualities that I described above in specific ways. They form a new approach and identity to truffle production, one with greater regard for professionalization — that is, greater value and emphasis on optimizing truffle production and making the pursuit seem more feasible and reliable for newcomers who may want to invest or partake in the industry. This is a professionalism similar to what Heather Paxson found in the cheese world, at the well-publicized Jasper Hill Farm. This is a departure from concerns over frugality; it is a willingness to, as one grower put it to me, "throw money at the orchard," in order to make it produce as quickly as possible. It is a professional ethic that de-emphasizes the process of gathering knowledge on one's own—in an embodied sense and regional sense—in the interest of producing a consistent and high-quality crop of truffles. This is done with the economic motive of selling truffles, of course, but also with an eye to building a regional reputation for high-quality melanosporum production that will fuel other profit-generating activities such as agro-tourism, the sales of land for truffle orchards or established truffle farms.

CHAPTER 3: Soil Drugs of the Future: Mycorrhizal Inoculants for Industrial Repair or Reform

A decade into the twenty-first century, a wave of agricultural conglomerates that produce chemical fertilizers began to manufacture symbiotic microbes. These commoditized fungi and bacteria take the form of "biofertility" products (Parnell et al. 2016). Marketers in this industry now push a public relations campaign that distinguishes twentieth-century advances in chemistry that enabled potent fertilizers from twenty-first century forms of crop fertility that will come from biotechnology. This is an effort to make industrial agriculture more compatible with a long-building trend in public perception (in places where industrial agriculture has dominated) in which chemical products are seen as effective for plant production and yet are also responsible for increasing environmental ills and human disease.[102] Bio-technologies are slated to break through this impasse. These technologies are not the recombinant genetics that gave the world Roundup Ready crops; nor are they employing refined "gene editing" techniques such as CRISPR (Stone 2010; Chen et al. 2019). Instead, the heavily promoted turn away from the

---

[102] Rachel Carson's mid-twentieth century popular writing, which preceded this environmental movement, was a watershed in public awareness of the harm of chemical products (Carson 1962). For European antecedents and prior occupational health initiatives, see Davies (2013) and Nash (2006).

chemical and toward the biological in agriculture is part of the burgeoning sciences of host-microbe interactions. Once isolated and esoteric, these scientific disciplines have been fueled by new molecular tools and expanding societal interest in biotechnologies such as human fecal transplants for gastrointestinal disease (Yong 2016) and microbes manufactured for landscape restoration, which includes breaking down hydrocarbons—such as oil spills—and the bioaccumulation of heavy metals—which concentrate with the use of some pesticides (Singh 2006). The new industry, which I follow industry insiders in calling BioAg[103], seeks to capitalize on this interest by commoditizing symbiotic microbes for large-scale agriculture. BioAg boosters talk of a paradigm shift in agriculture, one that expands far beyond niche practices such as organics and will include those farmers who do not identify with environmentalist concerns, but with the desire to reduce costs.

Still, boosters of BioAg promote an eco-revolution that reflects recent understandings of the "ecological services" that come with thriving microbial communities (Gianinazzi et al. 2010). BioAg practitioners work with bacteria and fungi that they have found to live beneficially with plants. Researchers call these *symbiotic* relationships. BioAg is an initiative to transform these complex relationships into shippable commodities that will be effective in disparate soil ecologies. A microbe becomes an inoculant after it has been abstracted from a soil, individualized (cultured in a laboratory), and then sold in a granular medium or suspension that can be applied to soils far and wide. Inoculant is a familiar word to epidemiologists and public health professionals; in BioAg, however, inoculants are not used to vaccinate against microbial communities—instead of jumpstarting immune systems, they jumpstart microbial ecologies.

---

[103] The name BioAg comes directly from the BioAg Alliance formed by Monsanto and Novozymes. Although pest control (via the use of beneficial microbes and insects) is a larger and more developed component of this industry, my focus is on what industry insiders call biofertility products.

Some researchers prefer to call these “biostimulants,” since they stimulate or build microbial communities that will in turn benefit plants via fertilization or functions such as pathogen antagonism, improved soil structure or water uptake.

Even the most optimistic of BioAg boosters acknowledge the difficulties of creating these technologies. Their profitability relies on two factors: first, the ability to culture the microbe cheaply and in large quantities; second, guarantees that the microbe will bring the desired effect to a wide array of agricultural contexts, be they soil types or crops. Historically, only one group of bacteria, rhizobia, has made the cut and entered industrial agriculture as a biofertility product.

A question that underlines this chapter (and the next) is what kind of change those who design and promote biofertility inoculants intend for the soil drugs to bring to agriculture. Are the products designed to uphold a fossil-fuel intensive, universalistic and reductive style of agriculture, such as spread around the world during the Green Revolution (i.e. the development of new wheat varieties that offer higher yields but that make farmers even more reliant on elaborate irrigation systems, synthetic fertilizers and pesticides)? Do they plan to uphold this sort of industrial agriculture by bringing incremental changes that will reduce environmental impacts, namely runoff of chemical pollution. Or are soil drugs part of a greater change in agriculture, one done with the far greater urgency that comes with the insistence that industrial agriculture has long caused undue social and environmental harm?

To answer these questions I turn to an emergent product line of BioAg: soil drugs made from a symbiotic group of fungi called arbuscular mycorrhizal fungi (AM fungi). I will describe the motives and methods behind the two dominant ways to create *AM inoculants* (as I will call biofertility inoculants made from AM fungi). These are *in vitro* and *in vivo* methods of production. *In vitro* inoculum production occurs in petri dishes or bioreactors with (near) sterile conditions. The *in vitro* system for producing AM inoculants includes only one known strain of AM fungi and the excised roots of one (sterilized) plant host, which enables this fungus to grow (I will explain below how roots can grow without the aboveground portion of the plant). *In vivo* inoculum production occurs in mycorrhizal researchers call "pot cultures." These are pots or troughs filled with a soil or soilless medium (vermiculite, clay substance) that has been treated to some degree (fumigated, pasteurized) to limit potential pathogens or microbes that may compete with the desired AM fungus. Spores of the desired AM fungi are added to the soil along with young, fast growing plants on whose roots these spores will germinate. As this is not a sterile method of inoculum production, the AM fungi will multiply along with associated bacteria and other fungi. Unlike commercialized *in vitro* methods for producing AM inoculum, which, for the time being, are only compatible with one species of AM fungi (*Rhizophagus irregularis*), *in vivo* systems often include many species of AM fungi. Equally important to those who follow *in vivo* methods are the associated microbes—all those life forms within the soil zone where mycorrhizal fungi meet roots, the *mycorrhizosphere*—which researchers increasingly argue are necessary if AM inoculants are to bring benefits such as pathogen antagonism, the converting of phosphates into a bioavailable form, improvement of soil structure (Martin et al. 2018; Linderman 1988). I discuss how AM inoculants made in either *in vivo* or *in vitro* systems of production are often designed and marketed to bring drastically different outcomes, these range from a mere supplement for chemical forms of fertilization to an initial step to the greater repair of damaged soil ecologies. In other ways, I suggest, the two forms of AM inoculum serve the same purpose, and are sold together.

When it comes to what AM inoculants can bring to industrial agriculture, André Fortin, a key informant during my fieldwork and the scientist who helped create the *in vitro* system for producing AM inoculants, touts its connection to twentieth century industrial agriculture. He co-authored one of the best-selling books on the topic, entitled *Mycorrhiza: the new green revolution* (Fortin et al. 2016). As the book's title makes clear, Fortin is unapologetic about industrial-intensive agriculture. In his view, the system as a whole is not bad. The problem is that microbes have been left out.

Michael Amaranthus, the founder of an AM inoculant company in Oregon who has similar industrial ambitions, prefers to cast the symbio-products in a deeper shade of green. Instead of evoking the work of Norman Borlaug, Amaranthus turns to Rudolf Steiner, Sir Albert Howard and Masanobu Fukuoka—iconic figures with alternatives to industrial methods. In a 2013 article for *The Atlantic* entitled "Healthy Soil Microbes, Healthy People," Amaranthus lists these heroes of "alternative" agriculture before going on to say:

> Fortunately, there is now a strong business case for the reintroduction of soil microorganisms in both small farms and large-scale agribusiness. Scientific advances have now allowed us to take soil organisms from an eco-farming niche to mainstream agribusiness.

This article, co-authored by Amaranthus and the political economist Bruce Allyn, was clearly aimed at a non-agrarian audience. It sought to give BioAg greater epistemic and technical footing by intertwining vanguard biomedicine with BioAg technologies. The premise of the article is to link the microbial technologies of the soil with similar forms of therapy that have been successful in healing human guts, for instance "probiotic" dietary supplements and fecal transplants that amend or replace microbial communities in human stomachs that are not functioning properly (see Montgomery and Biklé 2016). The article's take-home message is clear: recent advances in microbiology have clarified and given credence to those vague and mystical methods of "alternative" agriculture (e.g. biodynamic farming which has long argued for the importance of soil lives). BioAg promoters argue that it has sorted the wheat from the chaff, and packaged the former into what Amanthus and Allyn call the "soil drugs of the future."

I argue that the remarkable feat of BioAg is less the "reintroduction" of microbial symbionts into industrial agriculture than the creation of a few *symbio commodities* that are able to survive within the very industrial infrastructures that initially precluded these microbial communities. BioAg allows the continuation of intensive industrial practices (inversion tilling, sustained monocultures, the liberal use of pesticides and fertilizers) that severely stress the microbial communities in soil, and greater agro-ecologies—practices that I refer to below simply as industrial."[104] Ironically, rather than ushering in a sustainable form of agriculture, BioAg products (as currently produced and used) do more to uphold long-standing agricultural conglomerates and their reductive approach to crop production. Farm advisors and inoculant company representatives told me that inoculants are most often used in tandem with chemical products: a farmer saves money by needing to buy less chemical product, even when factoring in the cost of the inoculants. The bottom line is that AM fungi do not bring the same growth response as chemical fertilizers— they do not *add* nutrients to the soil but translocate nutrients.[105] For this reason, if a farmer does not follow practices that build soil organic matter and enable larger communities of soil microbes to thrive, inoculants are little more than a way to make fertilization inputs more efficient— equally important, for farmers who face pressure from

---

[104] I use the shorthand of "industrial" agriculture fully aware that agro-ecological destruction may owe more to the *intensity* of such practices than any scaling (see Lyson 2008). For more on agro-ecological health and the impacts of scaling, crop specialization, and other intensive uses of arable land, see Gliessman (2014).

[105] During fieldwork I heard a few researchers argue that AM fungi do "nothing" to add nutrients to soil and therefore will never replace other fertilizers. It was more common, however, for researchers to explain how AM fungi are able to mine and convert rock phosphates into bioavailable forms. In this way AM fungi are able to create nutrients where none had previously existed.

"downstream" communities and landowners, is the ability to say that they have taken measures to prevent runoff of chemical products.

The "strong business case" for AM inoculants requires more than greater efficiencies in crop fertilization. If these products are to usher in a new agricultural paradigm, they must also be marketed as a tool for "rebuilding" damaged arable soils. If the products are to be profitable, companies must promote them as effective across crops and soil types. This is achieved through what I call the "clean slate" rationale, which says that soilscapes subjected to severe tilling and heavy doses of fertilizers and pesticides have been wiped clean of functioning microbial communities.[106] The clean slate rationale reduces millions of acres of arable land, across the globe, into a single category, one ripe for inoculation by industrially-produced AM inoculants. This absence of microbial communities has reached a point of crisis, particularly looked at after the recent popularization of host-microbe interactions, whether in mammalian guts or soil ecologies. Narratives such as "microbes are us" (Gilman and Rees 2018) and "the soil will save us" may concern environmentalism (Ohlson 2014), gardening (Hemenway 2009; Lowenfels and Lewis 2010), or biomedicine (Collen 2015). BioAg has now found its own role within this context; it has a line of products with which it responds to the agro-environmental crisis.

With this formula of environmental crisis plus commercially available repair, BioAg adheres to a logic in which capital accumulation can come through environmental restoration, what Amber Huff and Andrea Brock (2017) call "accumulation by restoration. This is part of a broader trend in the "economy of repair" (Fairhead, Leach and Scoones 2013) that actively seeks to conserve microbial life through the use of inoculants or "probiotics," whether in human

---

[106] This argument has a long and wide-reaching history. While not all of these authors flatten industrial arable soils into one category, they do provide their own rendition of the argument that these soils lack microbial diversity, and in turn, benefits to crops. For agro-environmentalist takes see Shiva (1993), Jackson (2010) and Ingham et al. (2000); for an industrialist take, see Conway (1997); for an agrarian take, see Andersen (2000).

bodies, arable soils, or less-managed landscapes (Lorimer 2017). As Christopher Henke (2008) asks, what kind of repair is at play? Is this a movement concerned with the revitalization of agro-ecologies? Or is it more so the latest act of maintenance for an agricultural system that a growing segment of society sees as inherently unsustainable?

The crisis and need for repair that has brought BioAg into existence relies on a discursive split between the biological and the chemical. It draws on a form of value generation that a multidisciplinary group of theorists call "biocapital," the configuration of life forms into lively commodity forms (for a genealogical overview, see Helmreich 2008). As commercialized symbionts, AM inoculants find further bio-value. These are value-added bio-products that exploit current ecological, ethical and cultural values of symbiosis. They are thus a particular form of biocapital, what I call *symbio-capital.*

In using inoculants to declare a departure from twentieth-century chemical-based agriculture, BioAg marketers signal a self-initiated move into what social theorists have called a "reflexive" or "late" phase of modernity (Beck 1992; Giddens 1994). In second-phase modernity, the ecological limits that were tested (and crossed) by first-phase modernity become an inescapable conundrum; a separate stage of modernity has come into being precisely to amend the socio-environmental ills caused by the first phase. The analytic of ecological modernization has shown one manner in which such ecological limits have been dealt with; the premise is that preserving ecological health need not retard economic gain, this is analogous to the language of "sustainable development" which has become ubiquitous among governmental and intergovernmental bureaucrats.[107] Employing still more modern techniques to fix the mistakes of

---

[107] Ecological modernization is an umbrella term that has been used to cover state and suprastate policy (Mol 1996), as well as the eco/green discourse that is increasingly used in scientific outreach, industry reports and entrepreneurial initiatives (Hajer 1995). I use the analytic in a descriptive sense, to track the conditions that gave rise to win-win discourse, and its importance in late modern societies (see Buttel 2000).

past modernities has proven profitable. According to Arthur Mol (1996), an early scholar of ecological modernisation, the "theory concentrates on a process of modernising modernity by repairing a structural design fault of modernity: the institutionalized destruction of nature" (Mol 1996; 305).

Biofertility products thus fit into a broader eco-modernist trend. They offer a "sociotechnical imaginary" (Jasanoff and Kim 2015), a version of what Heather Paxson and Stefan Helmreich (2014) call *model ecosystems*, which pose microbes "as promising tokens for reimagining nature as it could or should be" (on bio-potentiality, see Taussig et al. 2013). In the case of BioAg, this becomes the promise of bio-industrial repairs that enable the continuation of industrial-scaled and highly mechanized and specialized farms.

Although Fortin and Amaranthus regard industrially produced microbes as the only viable future for global agriculture, many of their peers with whom I spoke feel differently. These mycorrhizologists, who are equally venerable and active in the international community of mycorrhizal researchers, note that we have only just begun to understand the diversity of AM fungi. They critique the global use of industrially produced mycorrhizal spores as a hasty and foolhardy modernist scheme that ignores environmental risks.[108] This critical voice also laments BioAg's inability to address the mechanized and industrial infrastructures (Fitzgerald 2003) that have neglected arable microbial ecologies and made agriculture reliant on petrochemicals and concomitant geopolitics (Mitchell 2011). If commercial inoculants are not accompanied by structural changes to industrial agricultural practice, these informants told me, we cannot expect them to repair broken agro-ecologies.

---

[108] For critiques of AM inoculants in particular, see Hart et al. (2017). For more on researchers discovering fungal diversity as it becomes extinct, including the potential ecological and climatic importance of this diversity, see Zak et al. (2019) and Pringle et al. (2011).

How are we to evaluate the win-win promises of biofertility products? How are we to determine whether greenwashing (Harré et al. 1999; Bowen 2014) or significant eco-repair are at play, and in what ratio? What is really being repaired, by whom, and to what extent? In his study of industrial agriculture in late twentieth-century Salinas Valley, California, Christopher Henke (2008) provides a useful framework. He distinguishes between repairs designed either to maintain or to transform status-quo conditions. Despite their desire to transform certain practices, such as the overuse of chemical fertilizers and pesticides, Henke tells of farm advisors whose advice is limited to suggesting only incremental changes, which do more to sustain those agricultural practices that pollute human bodies and environments than to ameliorate the situation. I find something similar among researchers and industrialists who design BioAg commodities. I argue that industrial biofertility products, as they currently exist, offer *maintenance repair* in that they provide just enough mitigation of environmental pollution so as not to cut into the continuing profits of status quo agricultural companies. BioAg's transformative agro-ecological repair remains a biotech promise (see Fortun 2008), a potential that is real but could materialize in many ways.

Chapter Roadmap

Part I of this chapter provides historical context to the formation of industrial biofertility products. This history begins in the nineteenth century with the rise of crop fertilization that came from off-farm sources, such as mined minerals and bat guano. I discuss how, at the end of the nineteenth century, a group of nitrogen-fixing bacteria called rhizobia was transformed into an inoculant that also brought crop fertilization. The relative ease of developing and promoting rhizobial inoculants contrasts with the difficulties of commercializing AM inoculants. I present this history to show antecedents to BioAg, and to show how biofertility inoculants in the twentieth century were marketed and promoted differently than they are in the twenty-first century; namely, in the twentieth century inoculants were not sold with claims of environmental sustainability.

This historical context sets up a discussion on how AM inoculants commercialized and became industrial products. Part II centers on the creation of an *in vitro* experimental system that would become the dominant system of production used to create AM inoculants. I employ Hans-Jorg Rheinberger's (1997) framework of "experimental systems" to explain the material productivity of the *in vitro* system. This is a mode of producing soil drugs that can handle large quantities while producing a product that can be guaranteed "contaminant" free. This section draws on fieldwork in Quebec, with a key architect of the *in vitro* system used to culture AM fungi and a company that may still be the world's largest producer of AM inoculants.

Part III brings in voices from the global community of mycorrhizal researchers who question the extent to which inoculants produced using this *in vitro* system actually bring promised "ecosystem services." A few of these critics produce their own soil drugs. But they do so using a contrasting *in vivo* experimental system, which they call more "holistic," claiming that their products are better able to deliver the ecosystem services (nutrient uptake, soil aggregation, pathogen antagonism) promised by inoculant producers who use *in vitro* systems.

Part IV focuses on the other half of commodifying soil drugs: creating *spaces* in which they can be guaranteed efficacious. I describe why BioAg boosters are so confident that the new products are able to boost plant production, on a global scale. Justification for soil drug efficacy across soil contexts comes down to what I call the "clean slate rationale." This is the argument that soil microbial communities in industrial arable soils have been so disturbed that they can no longer provide "ecosystem services"—*and*, just as importantly, that any microbial communities that may exist in industrial soils are unable to interfere with soil drugs in their role of bringing ecosystem services (back) to agricultural soils. This is an important claim that wipes away regional and local *ecologies of production*, so as to sell standardized inoculants to standardized (via industrial destruction) soilscapes. To think through the clean slate rationale, I engage with what scholars from across the social sciences and environmental humanities have called "second nature," that is, a built or organized form of nature, which stands in contrast to a nature less manipulated by humans (Cronon 1992).

The chapter concludes by showing how both methods of inoculum production seek to imbue a salable product with the rapidly expanding symbio-values and biocapital of mycorrhizal and host-microbe interactions writ large. Finally, I reiterate my core argument: that the greatest value in biofertility inoculants, as they currently exist, is at the service of industrial agricultural practices; by providing minimal mitigation of environmental and occupational health, they allow the vast majority of these practices to continue. While AM inoculants may help to "green" agriculture, their incremental approach also serves to preclude more transformational agricultural change (a topic that I take up in Chapter 4).

PART I: The Exemplary Biofertility Commodity

Separating the Chemical from the Biological

BioAg relies on a foil: chemical agriculture. This dichotomy arose in the mid-nineteenth century, when the innovative German chemist Justus von Liebig sought to make crop fertilization more efficient. Liebig had already made use of the then burgeoning field of applied chemistry with his invention of shippable meat gels (a precursor to meat bullion products) under the company name Liebig's Extract of Meat Company (Brock 2002); he wanted to apply the same chemical reduction to the production of much more complex plant-soil interactions.

Prior to the mid-nineteenth century, crop fertility was aided by the use of manure and compost from on-farm ruminants or crop residue. Farmers also enhanced fertility by strategically planting a variety of crops in the same field, rotating crops over time, or letting fields remain fallow, with the idea that soils would regain their physical structures, if not nutritive qualities (Karlen et al. 1994). Liebig saw time-consuming and laborious practices, such as raising animals for their manure, as unnecessary. He did not think that farmers should have to bother with planting crops of lower market values or follow the even more economically wasteful practice of letting fields lay fallow. If Liebig could pinpoint what he saw as the nutritive vagaries of soil (which elements, in compost, were most important for a plant), he could make such inefficient practices a relic of the past.

As Liebig experimented with supplying and withholding certain minerals in the soil, he demonstrated the extent to which plants rely on a few macronutrients. He found nitrogen, phosphorus and potassium (N-P-K) to be the greatest limiting factors to plant growth, and argued this case regardless of context: deplete soils of nitrogen or phosphorus and growth slows, plants yellow, and fruiting becomes lackluster; add materials with a high nitrogen or phosphorus concentration (guano or mined minerals) and the effect reverses. Liebig summarized his findings with the "law of the minimum": plant productivity is dictated not by a soil's overall material composition but by whichever of Liebig's shortlisted chemical elements is in the shortest supply.[109]

---

[109] Recent scholarship identifies German agronomist Carl Sprengel as having argued for the law of the minimum before Liebig (van der Ploeg et al. 1999). The belief that both men deserve credit for this work is evidenced by The

This was a revolutionary move. It countered popular agronomic opinion which held that complex biological and chemical materials and properties (extending far beyond three elements) were why compost was so critical for sustained plant health.[110] Liebig was convinced that vague suppositions about unseen soil organisms could be thrown out and replaced with a neat list of mineral or chemical components. He reduced the biochemical complexities of compost and crop rotations to N-P-K.

In the second half of the nineteenth century, the effects of a N-P-K regime for crop fertility became undeniable, and irresistible. Farmers with access to markets with N-P-K-rich materials, such as guano and sodium nitrates, quickly came to accept these new commodity inputs as equal if not superior to bulky compost and manure.[111] As global markets formed around transportable materials such as dried guano and mined minerals, the toil of raising animals for their manure and then laboriously spreading it on fields became obsolete. Materials that were transportable and rich in N-P-K followed drastic boom and bust cycles. Historian Edward Melillo (2012) argues that the "first green revolution" began with the exploitation of massive (but still exhaustible) deposits of guano and sodium nitrates from South America, commodities sold to farmers in North America and Western Europe. Fertilizers produced off-farm became even cheaper and more abundant in the early twentieth century with the spread of the Haber-Bosch method, an industrial means of transforming atmospheric nitrogen into a plant-available

---

Association of German Agricultural Experimental Stations, which awards the Sprengel-Liebig Medal for notable achievements in agronomy.

[110] Sir Albert Howard, who began his career in agronomy in the first years of the twentieth century, is a noteworthy example of someone who retained this old view of plant nutrition. A few decades later Howard even turned to mycorrhizal fungi (which were then little known to agronomists) as the biological answer to why compost was essential for plants (Gieryn 1999b). This discussion on indeterminate "forces" in the soil that lead to plant growth links up with the concept of "vitalism" that had a strong presence in late-nineteenth and early-twentieth-scientific communities (see Haraway 1976).

[111] There was scientific opposition to Liebig's prescriptions, which warned that short-term economic benefit came at the expense of long-term agroecological health (Howard 1943). But given the excitement for what would become known as biochemistry, and the economic practicality of an N-P-K approach, chemical reduction won the day.

form. Beyond agriculture, the method forever changed the physical makeup of nitrogen on a planetary scale.[112] By mid-century, instead of being confronted with limitations in soil fertility, agriculture's problem concerned the environmental consequences of overusing "cheap" fertilizers (see Moore 2015).

A Bio-commodity Amidst Chemical Profits

The chemical takeover of crop fertilization successfully replaced on-farm fertility sources with off-farm commodities. When coupled with new financial technologies that allowed farmers to acquire large quantities of fertilizers, agriculture entered a period of intensification and industrialization. Labor requirements dropped and profits increased as farmers did not need to deal with animals and their manure, the added work of crop rotation, or the loss incurred by planting crops with lower market values. But this transformation was not free of constraints. Farmers became reliant on the companies that supplied the new commodities. Goodman, Sorj and Wilkinson (1987) see this process as one in which on-farm labor and ecologies are "appropriated" by off-farm industrial facilities; concurrently, agricultural products are "substituted" with non-agricultural ones. In the case of crop fertility, the labor that went into raising animals and spreading manure is *appropriated* by international mercantile companies (global trade in guano, minerals or chemicals); *substitution* occurs as military systems (the industrial production of ammonia for World War I, the Haber-Bosch method) are later diverted to agricultural use.

Industrial appropriation of on-farm materials and labor is not limited to chemical fertilizers. At the end of the nineteenth century, a group of symbiotic bacteria called rhizobia

---

[112] This is because as an incredibly efficient method of fixing atmospheric nitrogen, the Haber-Bosch method rapidly accelerated a process that was limited by life forms that perform the same chemical conversion (Smil 2001).

went through the same process. Rhizobia live symbiotically on the roots of leguminous plants (soy, clover); they form root nodules that "fix" atmospheric nitrogen into a plant-available form. Nodules are strung like a necklace on roots, and have a diameter of 3-5 centimeters. They are visible to the naked eye, which helps explain why civilizations, from the ancient Romans to the Aztecs (with their "three sisters" of maize, beans and squash), insisted on planting leguminous and non-leguminous crops in the same field, this way the nitrogen-fixing bean plants would replenish the nitrogen used by the squash and beans (Mazoyer and Roudart 2006). That bacteria created the nodules and provided plant-available nitrogen in the process was indisputable even in the 1890s, a time when Louis Pasteur campaigned to eradicate and prevent microbial growth writ large (Latour 1988). Rhizobia had forced researchers to accept that some of the newly recognized organisms were "good," and that their ability to fertilize crops had bio-commodity potential.

The indisputable plant-fertilizing abilities of rhizobia did not usher in a return to pre-Liebig forms of crop fertility. Agronomists did not turn against the recently adapted practices of monoculture and chemical fertilization that reduced soil microbes such as rhizobia. They did not advise greater crop diversity (crop rotations or intercropping with legumes); nor did they insist against microbially disruptive practices such as inversion tilling or the heavy use of chemical-mineral inputs that led to high soil salinity. Instead, agronomists strove to make rhizobia fit an agricultural system that was increasingly mechanized, homogenized, and expanding in acreage. They took advantage of its physical properties, which enabled the microbes to be converted into commodities produced in centralized manufacturing facilities and sold seasonally to farmers. Commodified, rhizobia looked just like mineral fertilizers. As the agricultural chemist Frederick

Guthrie wrote in 1896, rhizobia "will prove to be one of the most valuable contributions ever made by science to practical agriculture."

In 1895, Lorenz Hiltner and Friedrich Nobbe were awarded patents for the production of rhizobial commodities in both England and the United States (Fred et al. 1932). Rhizobia became the first microbial symbiont to be commodified for industrial agriculture. The commodity took the form of an *inoculant.* Unlike Louis Pasteur's inoculants of pathogenic microbes in the form of vaccines, these were inoculants of "good" microbes—similar, that is, to Pasteur's inoculation of pasteurized milk with "starter cultures" of laboratory-grown strains bacteria to begin the process of making cheese. Instead of a small amount used to trigger an immune system, biofertility inoculants consist of vast amounts of what researchers call propagules: pieces of organisms with the potential to grow into new individuals, such as seeds (plants) and spores (fungi).[113] Bacterial inoculants consist of "colonies" of the bacterium in question. Transforming a bacterium into an industrial commodity requires that it is made visible on a glass plate, so as to be separated from all other life forms. Under such *in vitro* conditions, the bio-object can be manufactured at industrial scale, guaranteed free of contaminants and effective in any arable soil. Thus it has been brought into industrial circuits of capital.

Creating Symbiotic Bio-commodities

How, specifically, are microbial symbionts commoditized? Noel Castree (2003), a social geographer who has written extensively on bio-commodification, breaks the process down into six conditions. The first three—a*lienability, individuation, abstraction*—concern the internal

---

[113] In addition to spores, hyphae (fungal threads) and root fragments that contain AM fungi within can also be used as propagules. However, some AM species tend not to propagate via these non-spore methods. Spores have become the gold standard for AM inoculation. In this paper, I limit my discussion of AM inoculants to spores.

qualities of the product.[114] To begin, the life form must be alienated from its original environment. It must then be individuated, separated from all other life-forms, or rendered "on its own"—this is how one researcher translated the term *axenic conditions*, or the separation of an organism from all others.[115] Only once individuated can the organism be abstracted; in the case of biofertility inoculants, abstraction refers to a state in which the life-form-cum-product can be applied to disparate arable environments.

For rhizobia, this three-step procedure begins with identification of the bacteria in their environment. Rhizobia are discernable thanks to the characteristic root nodules that they form on a well-defined group of plants (legumes). Extracted from these nodules, the bacteria grow readily on a petri dish in the lab. Researchers go through a standard procedure of cutting away all other microbial life, which is made visible in the new glass environment. This procedure is called sub-culturing and it is done repeatedly until only the one desired strain of rhizobia remains. Once the strain is thoroughly individuated, it can be divided endlessly and grown out on numerous petri dishes, a process made possible by supplying the bacteria with optimal growth media. The procedure may also be scaled up in bioreactors. Once grown out, the bacterial cultures are suspended in a liquid or gel, or mixed into a powder. This is the *in vitro* commodity form, which can be guaranteed free of contaminants, and can be purchased affordably in large quantities every time an industrial farmer plants a leguminous crop.

---

[114] Castree explicates three more conditions that refer to the external qualities of a bio-commodity: valuation, privatization, and displacement. Value and privatization may come through government legislation that enables scientists employed by public institutions to profit from their research, or by enabling patents on life itself (see Sunder Rajan 2006; Jasanoff 2005; Rose 2007). Displacement involves both human and nonhuman life. With rhizobia, this is most clearly seen with "elite strains" (Herridge 2011) that are sold with the promise of outcompeting the rich diversity of existing bacteria, which do not work as well under the logics and material infrastructures of industrial arable management.

[115] Although experimental systems for axenic conditions are most common for microbes, they also exist for mice. For more on axenic mice, bio-commoditization, and biotech, see Haraway (1997).

Thanks to this *in vitro* system of production, rhizobial inoculants became a common fixture of industrial agriculture. In the early twentieth century, when governments from the U.S.A to Australia had seed breeding programs that supplied farmers with free seed (see Kloppenburg 1988; Bugos and Kevles 1992), rhizobial inoculants were often part of these programs. In 1939, ERPI Classroom Films Inc., the then leading educational film production company, released *Science and Agriculture*, which boasted of cutting-edge technologies surrounding the soybean plant. The ten-minute film featured rhizobial inoculants alongside technologies that turned soybeans into plastic-like materials (Burlison 1939). Across the twentieth century, rhizobial inoculants were not sold as alternatives to chemical-based products, but as complementary to them.

The distinction that many twenty-first-century inoculant companies make between the biological (natural) and chemical (not-natural) did not apply to twentieth-century bio-commodities. Twentieth-century farmers were not sold rhizobial products as a way to "repair" soil ecologies or to "restore" microbial diversity; the inoculants were rather an efficient form of crop fertility, just the same as industrially produced ammonia. In fact, rhizobia producers argued that they had manufactured optimized microbes that should replace the diverse local array of less efficient microbes already living in a farmer's soil (Herridge 2011). In this way, rhizobial inoculants were viewed as an improvement upon nature. Endemic microbial biodiversity came to be seen as ineffective and outdated compared to the manufactured strains, the latter being more convenient for the timescales and rhythms of industrial agriculture.

PART II: An *In Vitro* System to Culture AM Fungi

A Market for Mycorrhizal Inoculants

In the 1930s, researchers had only begun to identify the benefits that a type of mycorrhizal fungi called arbuscular mycorrhizal fungi (AM fungi) hold for agricultural soils. The successful commodification of rhizobia as an industrial fertilizer encouraged researchers to do the same with AM fungi. A 1933 article in *Nature*, on mycorrhiza in California orange groves, reads:

> In view of the existence of mycorrhiza as a regular phenomenon in many crop plants, it appears likely, therefore, that intensive study of the soil conditions controlling its development may be a matter of practical importance to growers (Rayner 1933).

In 1933, mycorrhizal researchers knew that AM fungi aid a plant's phosphorus and water uptake. But they did not know *how* this occurs; they were completely in the dark regarding the physiology and diversity of AM fungi, or which species of AM fungi perform these functions and under what conditions. At the time, a few agronomists recommended soil practices that would encourage the growth of the AM fungi already in arable soils (Howard and Howard 1947). However, the flourishing industry for rhizobial inoculants would make another way of incorporating mycorrhiza into industrial soils the norm. Rhizobial inoculants set a precedent for how AM fungi could be optimized in agriculture, establishing a marketplace for such biofertility products. With a thriving market for rhizobial commodities (today called bio-fertilizers), this inoculant form became the go-to mode of commodification for AM fungi. If agronomists at the time had had their way, AM fungi would be made into an alienated and abstracted commodity just like rhizobia had. There would be no need to take the politically difficult path of disrupting an entrenched (Vaughan 1996) and highly profitable agricultural system. Changing industrial agricultural practice so as to encourage the growth of AM fungi already in the soil would be a moot point if rhizobial and AMF inoculants were widely available. Agronomists even had a term for the use of rhizobial and AMF inoculants on leguminous plants: the "trinity." The latter inoculant would optimize the plant's uptake of phosphorus, while the former would optimize the uptake of nitrogen. This would take care of the two macronutrients most commonly lacking in arable soils.

But unlike rhizobia, AM fungi are not amenable to *in vitro* culturing. For most of the twentieth century, researchers tried but failed to construct an *in vitro* system for AM fungi. By the mid-century, AM inoculants existed, but their production was restricted to what researchers today deride as "pot cultures."

From Dirty Pots to Clean Plates

Figure I: "Pot cultures" from the 1980s. An example of *in vivo* production of AM fungi. Photo credit: André Fortin.

As Figure I shows, "pot cultures" are AM fungi cultured on the roots of plants in pots or confined troughs, using plant species such as onion or bahiagrass that have prolific root systems and lead to the rapid growth of AM fungi. After just a few months the roots and soil are chock full of spores. The inoculum takes the form of what are called propagules. These include spores—contained in root fragments or on their own—as well as hyphae, those fine fungal threads that snake throughout the soil. When using pot cultures, propagules are filtered from soil and other organisms to the extent possible. The end product may take the form of a bulky soil amendment, or a more refined product that some companies call a "root powder." However, inoculants made from pot cultures, or what are called *in vivo* products, cannot be guaranteed free of unknown organisms, including potential pathogens.[116] It was clear to agronomists that a successful AM inoculant would have to be produced *in vitro* (i.e. under sterile conditions). As they would learn, however, in comparison to rhizobia the procedure could not have been more difficult.

The principle hurdle in getting AM fungi to grow under *in vitro* conditions is that, unlike other types of mycorrhiza, they are "obligate symbionts." AM fungi cannot grow without a host present: without an amenable root tip nearby, the fungus can only survive for a matter of days. Barbara Mosse, a leading AM experimentalist of the twentieth century, pioneered a method to overcome this hurdle. She applied what botanists call "root organ cultures" to AM fungi. She excised strawberry roots from their aboveground portion and then coaxed them to grow on sterile growth media.

---

[116] Aside from the inclusion of unknown microbes, the inoculant product is more of a soil amendment than a refined fertilizer made up of a specific microbe; this is due to its bulk, and the fact that it lacks an efficient form of scaling. It is not suited to repeated use on industrial-scale farms in the way rhizobia inoculants are. Applying such an amendment to large-scale farms is scarcely easier than applying compost, that material Liebig and his ilk made obsolete in industrial agriculture.

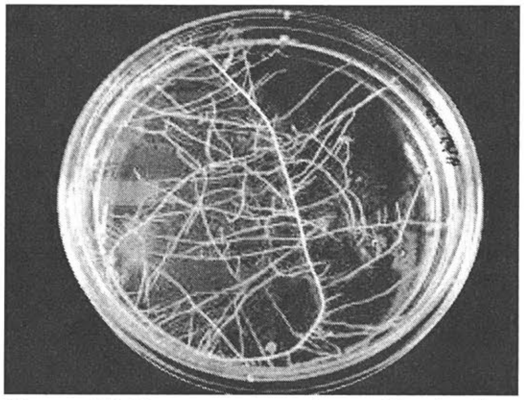

Figure II: Root organ culture. Excised carrot roots growing from growth media.

Despite years of tweaking the system (altering growth media so that both root and fungus would stay alive; experimenting with new species of fungi and plant), Mosse only managed to get one species of AM fungi to successfully associate with root organs. And even then, the fungus was not lively enough to complete its life cycle and produce spores (the material of inoculant).

Mosse presented this work at The University of Illinois in 1969, as part of the first ever conference devoted to mycorrhizal fungi. Few at the conference were working with AM fungi, and for that reason alone Mosse's work stuck out. Many saw right away the degree to which Mosse's experimental system was groundbreaking for mycorrhizal science (Hacskaylo 1971). André Fortin was one of the conference attendees who immediately saw the experiment's implications. When I met Fortin in 2016, in his hometown of Quebec City, he described his emotional state following the 1969 conference in vivid detail and with passionate attachment. Like many working in applied biology of the time, Fortin was both inspired and frustrated by industrial agriculture of the day. Fortin held equal (if contradictory) respect for the reductive and productivist research of Norman Borlaug as he did for the holistic and non-productivist arguments of Rachel Carson. He was impressed by the great yields achieved through mechanistic, silver-bullet approaches to farming, such as using hybrid wheat cultivars and abundant fertilization. And he was moved by the critical voices that explained how these changes decimated the lives within soils, as well as within human laborers and "downstream" ecosystems (Carson 1962; Sellers 1997; Nixon 2011). After Fortin had watched Mosse's presentation, he told me that "firecrackers went off in my mind." He changed his career path from work with ectomycorrhizal fungi (typically forest-dwelling fungi that produce mushrooms) to AM fungi.

As a graduate student, Fortin had worked with an *in vitro* rhizobial system in which root organs and rhizobial cultures thrived together (Raggio et al. 1957). He was convinced that Mosse was on the right track, and was confident that if he put in the work, he could create an *in vitro* system in which AM fungi would thrive, sporulate, and even serve as a commercial inoculant. Fortin's resolve to do this work came in part from an environmentalist ethical conviction and a belief that Borlaug's Green Revolution was on the right track. The problem, in his mind, was that this track did not go far enough: the industrial system was environmentally unsound because its architects had stopped short of incorporating symbiotic microbes.[117] He knew that in order to get mycorrhizal fungi into this industrial system, an *in vitro* system of production was needed.

Experimental Systems

Hans-Jorg Rheinberger's (1997) framework for "experimental systems" will help us make sense of the motivation and difficulty behind the creation of an *in vitro* system in which AM fungi are able to sporulate; that is, are strong and mature enough to create spores. According to Rheinberger, an experimental system is the most basic functioning unit of science (making). This brings our attention away from the organism itself, to the setting in which the organism takes material form and semiotic-cultural meaning. He describes a dialectical relationship between

---

[117] If AM fungi were doing their job of collecting water and phosphorus in the soil that roots alone cannot reach—while fungal hyphae and exudates improved soil structure—then farmers could reduce their fertilization, irrigation, and limit the need for inversion tilling.

"technical objects" and "epistemic things." Technical objects are the material, discursive, and cultural components that frame and hold steady the epistemic thing; the epistemic thing is the center of the experiment, that subject of study which is unknown enough to be a source of scientific findings. The success of an experimental system hinges on whether or not a researcher can strike the right balance between these two forces. Researchers must find the right amount of epistemic "fuzziness," which allows for a sufficient degree of what Derrida would call the *jeu des possibles* ("game of difference").[118] This balance enables researchers to come up with findings that are novel and exciting, while also legible and scientifically rigorous to the right community of practice (or right evaluators).

This begs the question: how do we determine whether or not an experimental system is successful? To be sure, Fortin was not only out to create a commodity for industrial agriculture. The benefit of an *in vitro* system in which AM fungi could complete its life cycle was clear (Declerck et al. 2005). For a twentieth-century microbiology that increasingly followed a reductivist methodology— an approach that abandons whole organisms let alone context for the smallest bits of life possible (Landecker 2007; Keller 2000)—*in vivo* systems or dirty pot cultures had epistemic things that were far too fuzzy, all manner of microbes lived within these pots. In Jacob's language, there was too much room for possibilities. With *in vivo* systems, it is extremely difficult for a researcher to know (let alone prove) that what is causing a response in plant growth is any particular AM fungus and not an array of microbes. And as I found out working with AM fungi in laboratories, sterilization of soil (or other medium), and of the AM fungus itself, is very difficult.[119] Additionally, researchers could not physically see processes

---

[118] Rheinberger's analysis is heavily inspired by Derrida, who used the term *jeu des possibles* (Derrida 1984). Français Jacob (1986) also employed the phrase in reference to the diversity of life.

[119] Considering the bacteria that live in various layers of the spore wall, and that killing this bacteria would render the spore inviable, some mycorrhizal researchers told me that the idea of a sterile spore is a fallacy.

such as spore germination, or how those fine fungal threads (hyphae) grew and connected with root-tips. Researchers knew that AM fungi played a role in numerous ecological functions, but, limited by a too-fuzzy epistemic object, they could not specify how or to what extent.[120]

"Success," in the eyes of researchers such as Fortin who labored to create an *in vitro* system for AM fungi, meant reducing the symbiosis as much as possible (how sterile could they go?), which would lead to the correct amount of epistemic fuzziness for what Thomas Kuhn (1962) calls a period of "normal" science for mycorrhizal researchers. But this is not all—*success* would also require that *in vitro* culturing be what Robert Kohler (1991) has called a "system of production." That is, a means to rapidly and prodigiously produce the bio-object in question, spores of AM fungi.[121]

Creating Vigor Under Glass

The work of Fortin and Mosse—who led teams of researchers in Quebec and England, respectively—of building out an *in vitro* experimental system put them at the vanguard of mycorrhizal science. In the 1970s, both teams added a critical technical object: a genetic modification that produces what are called hairy roots. This procedure starts with genes from *Agrobacterium rhizogenes*, a bacterium that causes crown-gall disease (large excrescences) on plants. When this bacterium is injected into root organ cultures, roots become vigorous, branch in hairy patterns, and any associated fungi follow in kind. With modified roots, AM

---

[120] On the other hand, when an epistemic thing becomes too determinate, too known, and loses all of its fuzzy qualities, it becomes a technical object. There are not enough surprises, or unknown possibilities, to make the novel finding that is required for scientific publication. Technical objects include everything from the agrobacterium used to create "hairy roots," the handful of plant hosts that have come and gone over the decades, the petri dish divided by micro-mesh, the root organ cultures, and the inoculum that these systems start with, which labs must buy or make on their own.

[121] Kohler provides examples of systems of production that include "breeder reactors" for geneticists whose research requires large numbers of mutated fruit flies (Kohler 1994); he also illustrates his analytic through the fungus *Neurospora crassa* (Kohler 1991).

experimentalists could tweak the growth medium to favor the fungus. Both fungus and root organ grew with far greater vigor. But still, the conditions were not optimal enough for the fungus to generate spores and produce the desired commodity.

The next critical step was a serendipitous find by Fortin, made while he was collecting fungi from under an ash tree near the town of Pont Rouge, just outside of Quebec City. Culturing the fungus back in his lab, Fortin quickly realized that the isolate grew far better than any other AM fungus he had cultured. He then conducted greenhouse experiments, which involved inoculating a series of plants with various strains of AM fungi. Compared to the others, what he came to call the Pont-Rouge isolate performed far better than any other (see Figure I: "INCONNU No 3" is the Pont-Rouge isolate).[122]

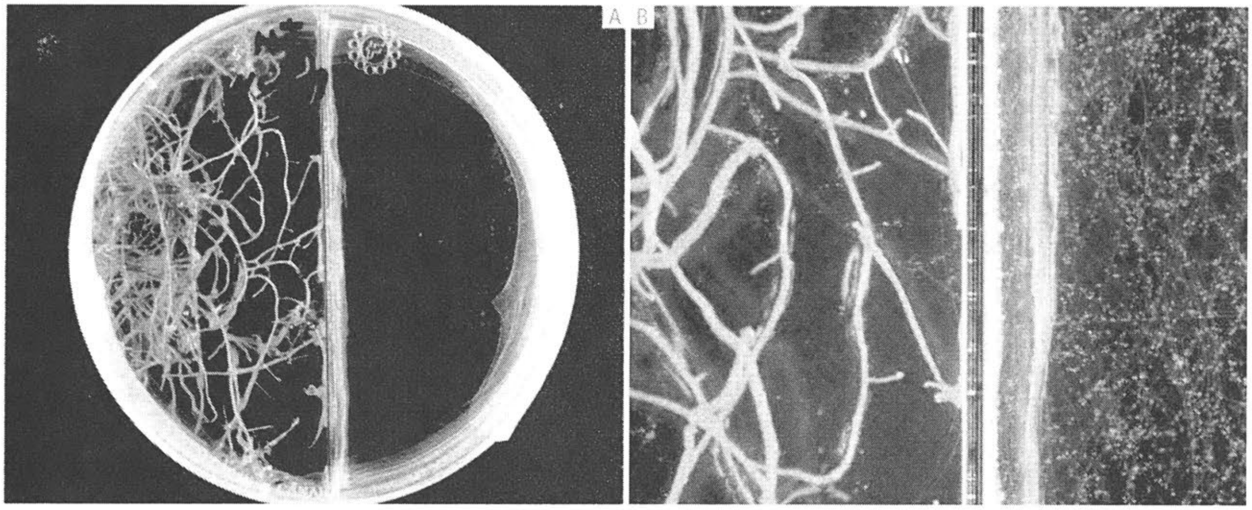

Figure III: The bi-compartment *in vitro* system. Photo credit: Marc St-Arnaud.

---

[122] The isolate is of a species commonly found across the world. Fungal taxonomists described the species in 1982 from specimens found in Florida (Schenck and Smith 1982)— they called it *Glomus intraradices*; today many researchers still use that name despite its official name (as enforced by the International Code of Nomenclature for algae, fungi, and plants (ICN)) of *Rhizophagus irregularis*.

Back in the lab, one further tweak was needed before the *in vitro* system became an efficient and scalable system of production. This came when Marc St-Arnaud, a student of Fortin's, created the bi-compartment system. He installed a divider down the middle of the petri dish, through which fine fungal threads could pass but not roots (see Figure III). This allowed him to use two growth media. One half (to the left) received a formula optimal for root growth; the other side (the right) had nutrients preferred by the fungus. As plant and fungus grew more vigorously, spore production rose precipitously. Additionally, St-Arnaud could take multiple harvests of spores from the second side without harming root growth on the other. With this system, millions of spores could be harvested from a single plate. The system has since been scaled up in bioreactors that can handle hundreds of liters of liquid medium; however, to this day, within such industrial conditions, only *Rhizophagus irregularis* is able to produce spores rapidly and consistently enough to make the operation profitable.

This *in vitro* experimental system has proven to be an immeasurable achievement for mycorrhizal science; it is the foundation of an entire mycorrhizal community of practice which has run with countless adaptations of the system, all of which, in Rheinberger's words, serve as "machines for making the future."[123] It is an experimental system that doubles as a system of industrial microbial production, giving agricultural conglomerates the confidence to invest in AM fungi as an industrial-scale biofertilizer. The *in vitro* system brings *isolation, individuation* and *abstraction* (Castree's conditions for bio-commodification) to the management of AM fungi. But with only one species of AM fungi that can be industrially produced—and sold by agricultural companies with deep economic interests in status-quo industrial agriculture—to what

---

[123] I describe some of these future making machines in Chapter 4, as they are used by researchers in France (see Rheinberger 1997).

extent can AM inoculants be the figurehead of a "new green revolution" that will repair soil and human health (as BioAg boosters claim)?

A few inoculant producers asked me this question before boasting that their production method for AM inoculants makes use of pot cultures, the method that architects of the *in vitro* AMF-culturing system thought would be left in the past. These producers insist on using a method of inoculant production that is more expensive, does not scale, and—due to regulations against transporting unknown organisms across state lines—is restricted to regional use. Moreover, inoculants made via the more expensive, less scalable and less transportable *in vivo* methods are often sold with an insistence that farmers also change their agricultural practice (reduce tillage and fertilizer use, increase crop rotations) so as to allow broader soil microbial communities to flourish.

In Oregon's Willamette Valley, I met a principal investigator of a public agronomy lab turned entrepreneur who has taken advantage of more sophisticated microbiology materials and methods (technical objects) to make *in vivo* experimental systems (pot cultures) an appropriately fuzzy epistemic thing. He has done this through the concept of the mycorrhizosphere, a concept that looks beyond sterile mycorrhizal connections to include broader microbial communities.

PART III: *In Vivo*: An Alternative to the New Sterility

Albany, Oregon

In the fall of 2016, I drove to a warehouse in Albany, Oregon, at the center of the Willamette Valley, to meet Robert Linderman at a warehouse of Plant Health, LLC, Linderman's mycorrhizal inoculant and soil consulting company. As we said hello, next to us on the ground lay a few fifty-pound bags of mycorrhizal inoculum that bore the company name. We talked in an empty room with a fold-out table for over two hours. He uttered the words "functional diversity" and "holistic" over a dozen times, while explaining why his *in vivo* practices make his product better than the rest:

> Well, what you see in the bag there, it's a holistic product. It's a pot culture system and I think that distinguishes us from pretty much everybody else...we use at least two species of plants in each pot.... All others use straight kitty litter or *in vitro*.

Linderman looks and speaks with the confidence and agrarian twang of a stereotyped landowner in the American West. He is tall, with a deep voice and never mincing his words. A large part of Linderman's identity concerns practicality; a strong and proud business sense. In one interview, he spoke uninterrupted for twenty minutes on how he garnered over three decades of funding—starting in the late 1970s and going through funding cuts and economic recessions—for his USDA Agricultural Research Service (ARS) lab that conducted research on soil pathogens and the ecology of AM fungi. "We were attuned to the problems, because we were working directly with industry, as opposed to people who were doing, I'll just say, molecular things, and don't even know what the problems are." But the problems Linderman focuses on—the problems that justify his self-description of "practical"—sharply contrast with the problems and practical-thinking that led Fortin to create a product accessible to industrial farmers the world over, starting with potato farmers in Quebec. Linderman, like other *in vivo* producers with whom I spoke, tends to keep his sights set on regional producers. We spoke mostly about what the Oregon Department of Agriculture categorizes as "specialty crops," including high-end berries (aronia berries, blueberries, grapes) and medicinal and aromatic crops (cannabis, basil).[124] These

---

[124] The ODA states: "Oregon is seventh in the nation in the production of specialty crops. Specialty crops include fruits, vegetables, tree nuts, dried fruits, horticulture, and nursery crops."

specialty crops require finely tuned and highly optimized soil conditions. We also discussed the use of inoculants to rebuild a soil's ecology, geared toward both farmers who have seen declines in yield and the restoration of native flora in land polluted or overgrown with "invasive" plants.[125]

Linderman's interest in AM fungi extends beyond applications intended to reduce the use of chemical fertilizers. Like Fortin, Linderman has a professional ethic of boosting rural economies by more efficiently growing healthy plants. Unlike Fortin, Linderman consciously rejects the *in vitro* advances described above. He sees *in vitro* inoculants as critical for research communities (see Chapter 4); as commercial inoculants, however, they miss the point of sustained soil repair. For that, one must turn to inoculants that contain broader consortia of microbes, not just a few sterile strains of AM fungi or beneficial bacteria. The need for a broader consortia of microbes to bring benefits beyond plant fertility is what Linderman refers to when he boasts that his product (unlike *in vitro* produced versions) is "holistic."

In Vivo Production: Pot Cultures

On one level, Linderman's method of production is a return to those messy pot cultures that dominated early-twentieth-century mycorrhizal practice. Linderman's holistic product, made following *in vivo* procedures, is a microbial "black box." It is filled with unknown processes, but produces desired results nonetheless. More specifically, *in vivo* production consists of "black pots." In these pots grow ecologies that are filled with microbes, known and unknown—assemblages of organisms that shape, and are a part of, the AM fungal inoculum that Linderman

---

[125] In this chapter I do not discuss all of the potential uses of AM inoculants. Aside from boosting the production of crops, they can be used in efforts to restore native flora that has a low survival rate when outplanting into often dry or otherwise extreme environments. A strong mycorrhizal connection can help a plant survive such conditions (Trappe 1977; St. John 2002).

sells. *In vivo* producers incessantly tell me that fungi and associated bacteria need to "grow up together"; this enables the intimate "teamwork" that Linderman says makes *in vivo* inoculants effective. Here, Linderman evokes the Belgian zoologist Pierre-Joseph van Beneden, whose 1876 publication *Animal Parasites and Messmates* brought the term mutualism to biology. It matters, Linderman says, that these microbes have "lived together," and for multiple generations. In other words, that they have been what Donna Haraway (2008) would call "mess mates."

I interviewed seven *in vivo* producers and visited their facilities; I found that these producers all speak proudly about having cultured the same microbial ecologies for decades. But these ecologies are hardly static, and instead are always evolving and adapting; they are grower-tested, well-curated, and thriving microbial communities. At its core, the production of *in vivo* inoculants is a matter of inspecting and transferring microbe-filled soil from pot to pot, and from one plant host to another. The method begins with a small batch of soil taken, for instance, from beneath a thriving row of crops. The producer then extracts spores of certain AMF species found present, which involves microscopy and taxonomy know-how. Identifying even those well-known AMF species is no easy task, involving morphological analysis of spores, whose differentiating features—such as spore wall thickness and ornamentation—are nuanced (see Figure IV). Unlike *in vitro* production suitable for commercial production, which is limited to strains of a few species, up to a dozen species of AM fungi can be grown using *in vivo* methods.[126]

---

[126] *R. irregularis* remains the sole species the can be scaled efficiently enough for most inoculant companies to remain profitable. That said, there are a few other AMF species that will grow under *in vitro* conditions, but they either grow more slowly or produce fewer spores. Researchers could not provide any specific number of AMF species that can be grown *in vivo*. The first difficulty lies with the taxonomic upheaval of AM fungi: in 2001, the group was put into its own phylum, only later to be demoted to a subphylum (Spatafora et al. 2016). Second is the question of which species can be practically cultured in sufficient quantities.

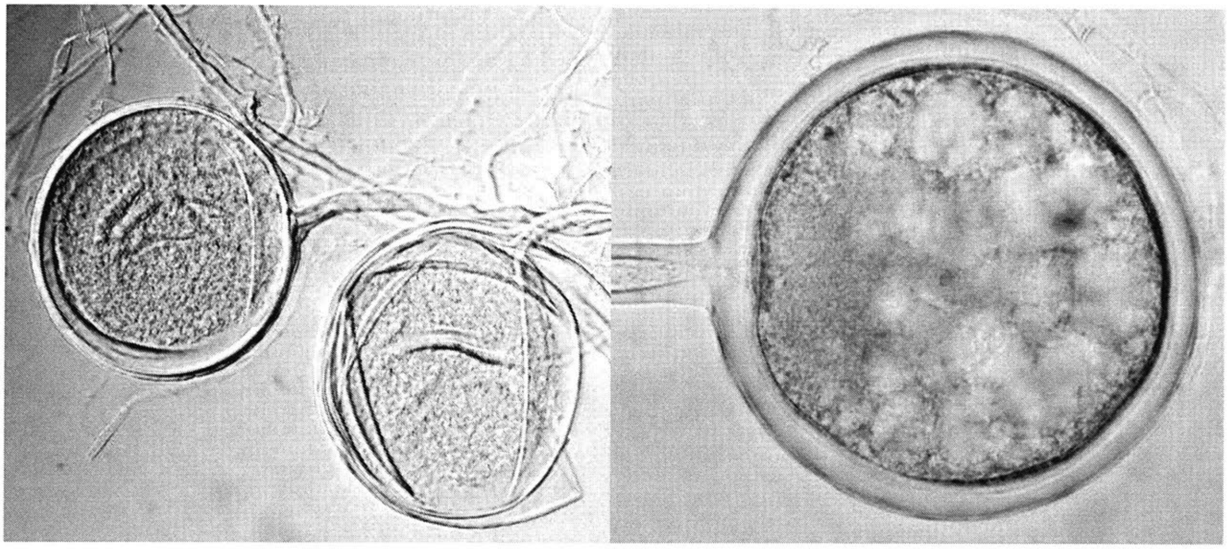

Figure IV: The morphological similarity of spores *G. irregularis* (left) and *G. clarum* (right). Photo credit: GINCO

These spores, which come with associated microbes, are then added to a potting mix that may include vermiculite, expanded clay, peat, or (nearly) sterilized soil. This media is then used to grow a plant with fast-growing roots, typically onion or bahiagrass. Depending on the company, this practice can look quite different (see Figure V).

Figure V: Large-scale *in vivo* production system, in beds rather than pots. Photo credit: Caroline Schneider

After a couple months of growth, with the pots chock full of spores (along with amplified levels of other microbes), the plants are cut and the soil filtered. *In vivo* inoculum is sold with varying degrees of filtration. It can be a highly filtered product and thus largely composed of AMF spores; a farmer can mix this "root powder" (as one producer calls it) with seed before planting. More commonly, the spore-filled soil is filtered to a lesser degree and then added to a "carrier," typically vermiculite or peat, which makes it easier for a farmer to apply the product to their soil; this is the end product that Linderman kept pointing to and demonstrably kicking as we spoke. It is applied directly onto fields, ideally placed in seedbeds beneath where seeds will be planted.

In addition to the quality and variety of spores that Linderman adds to his potted plants, which will in turn grow more AM spores, it is the media used in these pots that is crucial. Linderman insists on using a growth medium that encourages not just mycorrhiza, but the supporting community of life surrounding mycorrhized root tips, to flourish. In 1988, Linderman coined a term for the indeterminate and innumerable microbial communities that flourish in this zone of the soil: the mycorrhizosphere. This, he claims, is what makes his product better than the rest.

The Mycorrhizosphere

In 1904, the now famous soil scientist Lorenz Hiltner defined the rhizosphere as the zone influenced by the nutrients released by roots. But if nearly all root tips engage in the mycorrhizal association, and if exudates and chemical signaling to and from root symbionts impact this zone more than any microbe or root on its own, then should we not speak of the mycorrhizosphere? This is precisely what Linderman proposed in a research paper from 1988, in which he explains that "mycorrhizae significantly influence, qualitatively and quantitatively, the microflora [of soil] due to altered root physiology and exudation" (Linderman 1988;2). An increasing number of soil scientists now agree with Linderman's emphasis on roots-plus-symbionts rather than thinking in terms of roots alone (Ames et al. 1984; Gryndler 2000; Horton 2015; Powell and Rillig 2018).[127] As a group of leading mycorrhizologists put it, "The study of plants without their mycorrhizas is the study of artefacts. The majority of plants, strictly speaking, do not have roots; they have mycorrhizas."[128] Physically, AM fungi pervade this root-zone, their fungal mass in the rhizosphere is greater than any other microbe (Martin et al. 2018). They exude copious amounts of an exudate called *glomalin*, a sticky substance that creates the soil agglomeration that plants and farmers desire. Soil researchers believe that their physical and chemical properties attract

---

[127] There remains the question of whether AM fungi "lead" this consortia of microbes. Not all agree on what biologists call the "keystone" quality of AM fungi in the rhizosphere; that is, they do not agree with Linderman's description of AM fungi as the "quarterbacks" that lead other microbes in the rhizosphere.

[128] This quote, from May 25, 1993, comes from the Committee for the International Bank for the Glomeromycota (BEG). As of 2019, it is still featured on the homepage of BEG's website: https://www.i-beg.eu/

certain microbes and preclude others, as evidenced by an increasing array of mycorrhizal "helper bacteria" that have a strong positive correlation with root growth (Garbaye 1994). Researchers find a negative correlation between the presence of these *helpful* bacteria and pathogens that infect roots.[129]

The qualities Linderman and other *in vivo* producers see and want to strengthen in soils are in sharp contrast to what *in vitro* researchers see and want to encourage in the industrially worked soils for which they produce inoculants. *In vivo* inoculant producers do not view their product as a bio-fertilizer, but rather as a means of optimizing soil ecologies by providing plants with macronutrients such as phosphorus and nitrogen, along with water transport, pathogen suppression and soil agglomeration (see Rillig et al. 2019). *In vivo* production finds value in, and sells, precisely what cannot be alienated or abstracted. In this way, their bio-commodity breaks with the norms of bio-commodification, as described by Noel Castree. The product is cumbersome and unrefined—far from what Amaranthus calls "soil drugs" (in the *Atlantic* article quoted at the beginning of this chapter) and the pills produced by TERI in New Delhi (led by AM *in vitro* industrialist Alok Adholeya) (see Figure VI).

---

[129] This could be due to mycorrhiza and its associated microbes physically protecting roots by creating a barrier, or chemical signals and exudates that have direct antagonistic qualities. Even though this is his area of expertise, Linderman, like the majority of inocula producers, makes no mention of pathogen suppression on his label. Declaring his product to be a biocontrol agent would require EPA approval, which is not a straightforward or timely process. Most get around this by holding seminars or having a section on their company website expressly for the "basic biology" of mycorrhiza rather than any product claim.

Figure VI: Depiction of "formulation types" by leading technologists of AM inoculants. Photo credit: Adholeya et al. 2005.

Linderman's explanations of interdependent plant-microbe communities—in contrast to *in vitro* producers' tendency to highlight microbial absence—indicate a key difference not just in methods of production but in perceptions of arable soils. It is not that *in vitro* producers deny the existence of a complex mycorrhizosphere; rather, as depicted by Adholeya's poppable pills, opinions differ on *how* to best exploit these processes for farmers. Sure, *in vivo*-produced inoculants are a "better product," as a seller of *in vitro* produced inoculants told me. He clarified this statement by citing research that shows how bacteria associated with AM fungi also convert phosphorus to bioavailable forms, and how other mycorrhizospheric microbes prevent pathogens and give off exudates that improve soil structure. But, he stressed, inoculants produced in pot cultures are too costly and cannot be applied to large-scale farms. These latter qualities render the former ones moot. This is the same pragmatism that I heard, repeatedly, from Fortin throughout a string of correspondence which began with my visit in 2016.

Mixing Systems of Production (Having it Both Ways)

In 2016, Michael Amaranthus sold Mycorrhizal Applications (MA), Oregon's largest family-run and owned mycorrhizal inoculant company, to Valent BioSciences Corporation, a subsidiary of the Tokyo-based Sumitomo Chemical Company. In 2018 Amaranthus explained that he did as much as he could to promote AMF inoculants in Oregon (and elsewhere in the U.S.). He told me that agricultural conglomerates with "large research budgets" are now needed to bring the technology "to a global level." Some fifteen years earlier—Amaranthus, who earned his PhD with Jim Trappe and worked with mycorrhizal fungi for years as an employee of the USDA Forest Service—had still been running the company that he started with Eileen, his wife, out of their family garage. Amaranthus had begun modestly, collecting mushrooms whose spores could be packaged and used as inoculum that aids reforestation efforts (Trappe 1977). He then saw more profit potential with agricultural inoculants. He taught himself how to work with AM fungi, and built up the largest *in vivo* production facility in Oregon. Through tireless sales and promotion among Oregon's agrarian community (and beyond), Amaranthus became "Dr. Mike," the one with the soil drugs and the persuasive justification for their use. Linderman, who told me that he sold Dr. Mike his first batch of AM inoculum (Dr. Mike does not remember it this way), acknowledges that Amaranthus did do more than anyone else to make mycorrhiza known in Oregon. As Amaranthus did the rounds of conferences with soil scientists and other researchers, he began a relationship with Alok Adholeya, a technologically oriented mycorrhizal researcher who had already set up an *in vitro* production facility in India and was now doing the same in the

Great Plains of the U.S.. The ever enterprising Amaranthus then did what has become the norm in the mycorrhizal industry: he collaborated with Adholeya (in this case by hiring him) in order to gain access to cheaper and more plentiful *in vitro* inoculants. He then mixed *in vitro-* with *in vivo*-produced inoculants. Here was the best of both worlds: the economies of scale of *in vitro* production enabled high spore counts that have become a competitive edge in the flooded mycorrhizal inoculant market, while *in vivo* production provided AM species diversity, if at lower quantities.

With the spread of the *in vitro* system, *in vivo* production methods went from the only way to make inoculants to a rarely used approach. Most smaller companies such as Linderman's—which is still run by himself, with his daughter and son—now buy from global centers of *in vitro* production or produce *in vitro* themselves. Others, like Amaranthus, have sold out to BigAg. It has become a standard business strategy for chemical conglomerates to create or acquire "bio" divisions. Valent Bio Sciences is owned by a multinational chemical conglomerate. Premier Tech in Quebec is predominantly a manufacturer of petrochemical-based products (industrial water treatment tanks; varied agricultural products). In France, Guillaume Bécard, one of Fortin's students, started a "biological" division at a major, previously state-run company that sells chemical products. Formed in 2014, the BioAg Alliance comprises Novozymes and Monsanto. In Europe, Syngenta is one of the largest bio-subsidiaries, operating under the auspices of chemical conglomerates.

These vast centers of production that sell *in vitro* inoculum wholesale at rock bottom prices have upended Oregon's mycorrhizal inoculant industry. In 2018, the Oregon Department of Agriculture counted forty-three registered mycorrhizal products. While these are sold by at least a dozen different companies, the vast majority of this inoculum comes from just a few *in vitro* producers.[130]

This is an open issue for Amaranthus and others in Oregon's inoculant industry, who agree that the problem roots in a lack of knowledge, either among end consumers or employees at companies who buy from large producers and re-package the product (farm supply stores; garden centers). Amaranthus speaks with excitement about technological advances in AM inoculant production, but he is less sanguine about knowledge flows from mycorrhizal experts (whether lab-based or field-based) to farmers. Every employee at Mycorrhizal Applications who was involved in the company's early days told me how much Amaranthus valued working directly with customers (farmers) and how much he hated the fact that, as the company grew and started to sell to industrial-scale farmers across the nation, he was forced to go through "distributors" (the vast majority of large-scale American farmers buy products through these distributors).

Selling to distributors instead of directly to customers severs the flow of knowledge on the mycorrhizal symbiosis. This hampers the effective use of the products, an issue that is in the interest of large agricultural companies to fix. But it also limits the ability of a farmer to know when to stop using an inoculant, what the owner of a smaller inoculant company called an "exit-strategy." This owner prided himself on working with farmers who want to build healthier soils, and on his insistence on "weaning" his customers off his products. If they have "the biology back in their soil," he told me, then they no longer need his products. This was clearly his selling point, how he set out to differentiate his company from those such as Monsanto and Novozymes, who are now developing their own lines of biofertility inoculants.

---

[130] Indeed the ODA monitors this industry. Their 2018 results of testing label guarantees on mycorrhizal inoculants were dismal. Out of 43 products tested, only 4 "met their product label guarantees." (ODA 2018).

This argument for an "exit strategy" brings us back to questions of how and to what extent commercial AM inoculants, which are limited to so few isolates and are used without changes to agricultural practice, are able to repair the damage done to microbial communities. That commercial inoculants can restore soil health, and in a relatively context-independent manner, rests on a contested but common line of reasoning. This reasoning presumes, first, that industrial arable soils—across crops and continents—that lack symbiotic microbes lack them in the same way and have a similar make-up (this is to claim homogenized microbial destruction, or equal microbial absence). Making a judgment of standardized microbial damage tends to then lead to the further claim that farmers need not reform the practices that initially decimated soil microbes; instead, they can simply buy "soil drugs," abstracted and (purportedly) optimized versions of regional soil microbes, from the same companies that eradicated microbes in their soil in the first place. This comes back to what I argue is the underlying project of BioAg. As promoted by large agricultural companies, BioAg is less a paradigm shift in agriculture geared to soil restoration, and more a technological undertaking to find those select microbes that can be transformed into industrially produced and standardized commodities that will fit industrial agricultural systems far and wide. Achieving this feat requires more than any product alone; it also requires the creation of a standardized space in which the products will be consistently effective.

PART IV: Creating Spaces for the New Soil Drugs

Post-symbiotic Soilscapes?

In the early twentieth century, agronomists and agricultural company representatives told farmers that applying rhizobial inoculants would ensure that their crop had sufficient nitrogen. BioAg in the twenty-first century holds a more dire message. The new industry uses an environmentalist narrative that decries the loss of soil microbes due to twentieth-century industrial agricultural practice. BioAg then concludes this narrative with its own industrial solution. Promotional materials from Monsanto and Novozymes's BioAg Alliance are filled with discourses of "restoring" and "rebuilding" soil microbes. However, if only one species of AM fungi is being applied while practices that decimate existing populations continue, how much eco-repair is possible?

To understand the claims of eco-repair through which BioAg justifies itself, we need to unpack an assumption that is made about industrial arable land across the globe. The argument extends far beyond BioAg, and is in fact a common environmentalist narrative: industrial arable lands are some of the most unnatural places on earth. To use a concept from ecology now gaining traction beyond the discipline, instead of containing productive symbioses, these lands are in a state of "dysbiosis." This means that normally functioning symbioses are in disarray, which creates an open door for invading pathogens.[131] Even dirty city streets have greater symbiotic arrays of microbial communities. Citing dysbiosis as the cause, or form, of microbial disrepair on arable lands leads to what I call, following the words of an employee at a major inoculant company, the "clean slate" rationale. Proponents of non-industrial forms of agriculture, such as those who advocate non-western practices (Shiva 1993) or modern agro-ecological approaches (Altieri 1995), employ this rationale to advance particular modes of agriculture, which they see as superior to the now-dominant industrial form of plant production. The

---

[131] For popular usage of dysbiosis, see Yong (2016); for literature on industrial agriculture as more prone to pathogens, see Altieri (1995).

warnings about soil degradation issued by these advocates are a microbially aware iteration of those that reached their peak during the American Dust Bowl (Worster 2004), a time when concerted government action helped farmers restore soil structure and health. BioAg marketers have tailored this call-to-arms for their own ends.

As employed by BioAg, the clean slate rationale serves several purposes. First, it clears the chemical products themselves (or those who produce them) of culpability for environmental destruction. Blame instead moves to farmers who misused the products. Second, it shows agricultural conglomerates as following vanguard science and emergent technologies. The president of a large chemical company in France that has recently invested in a biological division told me that he (and the agricultural fertilizer industry as a whole) has always made the best use of whatever science and technology is available at the time. In the twentieth century (barring rhizobial inoculants), this was limited to chemical and mineral forms of fertilization; given the explosion of microbiology and molecular tools in the twenty-first century, agritech companies can now build industrial commodities out of symbiotic microbes. They can finally optimize and package a fungus-root symbiosis that has aided plant growth ever since plants evolved onto land 450 million years ago.

Believing that industrial arable lands have already been cleared of diverse life unique to the region is a requisite for the global sale of AM inoculants, this is justification for why the inoculants will work in such a wide array of soils. Specifically, the clean slate rationale keeps two critical voices quiet. First, it silences environmentalists (or like-minded researchers) who fear that such an aggressive "pioneering" species will outcompete or otherwise disrupt local communities of AM fungi.[132] Their interest is in minimizing the possibility of an introduced strain harming microbial agrobiodiversity (Bever et al. 2001); if the soil is lifeless, there is no risk. Second, it silences farmers who fear that microbes already present in their soils would prevent the inoculants from doing what their labels guarantee, namely providing positive growth responses that otherwise would not have occurred. If arable soils are effectively clean of AM communities, the introduced AM fungi can associate with crops and provide their benefits, unencumbered. With indigenous microbes out of the picture (the slate being clean), mass quantities of inoculants made from a single (ecologically dominating) species pivots from a liability to an asset, for farmer and environmentalist alike. It becomes plausible that even a single AM species could revive greater microbial communities.

To be sure, some BioAg companies promote AM inoculants as yet another form of plant fertility. As such, bio-fertilizers add a shimmer of green; they are what Miguel Altieri and John Farrell (2018) call an input substitution approach to sustainable agriculture. They are this century's line of fertilizers, made in harmony with twentieth-century industrial agriculture, but with the eco-friendly marketing that has become requisite (for nearly any company) with the ever worsening environmental ills of the twenty-first century. A core reason why chemical agricultural conglomerates pushed to create BioAg is because these new biological products can be used alongside the chemical ones. BioAg is thus about product diversification, not replacement. This makes the eco-repair claims of BioAg, as found in marketing materials and as I was told by researchers during fieldwork, all the more puzzling.

---

[132] The recent concept of "microbial community coalescence" underscores how little is known about introducing microbes to new environments (Rillig et al. 2016). Potential ramifications range from ineffective inoculum to invasive communities of microbes and the flattening of microbial diversity, in arable lands and beyond.

Damaged Second Nature

Soilscapes wiped clean of functioning microbial communities are well primed for capital accumulation by microbial restoration. Historian William Cronon draws on critical theories such as those by Neil Smith to discuss the "second nature" that comes about in the commodification of wheat in late nineteenth-century Chicago and its hinterland (Cronon 1992). Cronon discusses the flattening of rich diversities of wheat varieties, small family farms and specific means of growing and processing wheat. In the interest of keeping capital circulating smoothly, this diversity is flattened once it reaches Chicago's giant silos where it is funneled into just three grades. I do not use the term "second nature" to signal a separation of materials such as minerals, sand, wood and water (first nature) from human-impacted, culturally mediated materials such as concrete, steel and plastic piping (for more on accounts that hold nature as separate from culture, see Bowker 1995). I instead use "second nature" to signal a process of standardization, this is akin to what Neil Smith (1984) calls the production of space, in particular one that allows discrete (and homogenized) objects to be applicable to diverse soilscapes, and be legible among the agrarian and environmentalist values of varying societies, not to mention exchange value.[133] This is what I see at play with the clean slate rationale, as it flattens the diversity (or potential diversity) that persists even in soils exposed to abundant inputs and heavy tilling.[134] The clean slate rationale effaces these material realities; it is a discursive sleight of hand that renders billions of acres of arable land ideal candidates for a new wave of agricultural bio-products.

---

[133] For more on transforming organisms and environments into instruments for economic exchange and socio-cultural value, see the literature on biocapital (Helmreich 2008), as well as domestication (Cassidy and Mullin 2007).

[134] No researcher with whom I spoke could give me a clear answer on this point. They indicated that they have indeed seen soils in which they had a hard time finding any AM fungi at all, but then they would speak of dormant spores and even live AM fungi that reside in lower soil layers, and other propagules that would soon make their way into the soil. The now vast literature on AM fungi backs both arguments.

But the clean slate rationale does more than ensure a farmer that the product will work on her land, regardless of climate or continent. It speaks of a second nature in urgent need of intervention. It creates spaces in crisis, which may no longer remain productive without inoculants. AM inoculants are sold with declarations of a *damaged second nature.* As a commodity that can be produced affordably at an industrial scale and is touted as being able to perform on industrial arable lands writ large, these inoculants are an industrial fix for an already industrial second nature. Here is the crisis-and-repair logic of accumulation by restoration. Countless acres of arable soils, clean of microbes, become a unified horizon, ripe for BioAg commodities.

There are other visions of damaged second nature, and other means to accumulate capital from such spaces. Anna Tsing provides a contrasting yet complementary case of accumulation by mycorrhiza. In her ethnography of mushroom foragers in Oregon's forest, who seek another sort of mycorrhizal fungi popularly known as matsutake, Tsing describes the emergence of a "third nature," one in which industrial ruins—of forested not arable lands—have unintentionally enabled the flourishing of mushrooms of high market value. In this third nature, neither freedom-seeking foragers nor profit-seeking landowners are fully in control. It offers a way to make a living in the ruins of industrial forestry that is not tied to further industrial production. BioAg works to stop third nature from occurring in industrial arable land. Under BioAg, such land remains framed as damaged second nature: it is held in a state of disrepair that is best served by bio-products produced in mass by agricultural conglomerates. By acknowledging the disrepair, BioAg nods to the increasingly inescapable decimation of life caused by industrial agriculture (see Van Dooren 2014). But it yields only to the extent that is necessary. For the continuation of big-business profit gains, the broader industrial system must remain in place. Responding to environmental ills of their own doing, the chemical companies behind BioAg offer a way for status quo industrial agriculture to continue into the future.

Making Biotech Promise Convincing, Amidst Uncertainty

Inoculant companies can point to abundant research that shows how destructive industrial agriculture can be to soil microbial communities. Although most researchers I spoke with regard claims that industrial arable soils are clean of AM fungi as overblown, they do not contest that AM fungal communities have been negatively affected by industrial agriculture. Instead, they contest how these populations will re-establish themselves, under new farming practices or products.[135] Such debates multiply when, as one researcher put it to me, we start talking about "what inoculants do after they are put in the ground." This researcher continued by saying, "we have no strong evidence that they [the introduced fungi] persist."

BioAg boosters also admit to this uncertainty. Describing the current state of inoculant technology, Amaranthus told me that "we probably know 10%—no, less!—of what we need to know." Amaranthus did not make this statement out of despair; he rather exuded excitement about what he anticipates to be a period of immense growth for BioAg. Another optimistic researcher called the current technology a "stepping stone" for what is to come.

Richard Tutten and others writing about the "sociology of expectations" describe industrialists and business leaders who negotiate "desired futures" and construct expectations that "can become mutually shared guides for action" (Tutton 2011). Anthropologists of biology and biomedicine have shown how such potentiality is morally charged; it can inspire biological

---

[135] Emergent research on "subsoil" species of AM fungi (Sosa-Hernández Moisés et al. 2019) is poised to strengthen arguments that naturally existing AMF communities can reestablish themselves if farmers alter their practices (i.e. reduce fallow periods, heavy tilling and chemical applications).

experimentation and motivate investment across biomedical industries (Taussig et al. 2013). It is by leveraging such potentiality that BioAg advances from what Christopher Henke (2008) calls maintenance repair to transformational repair: the revolution of BioAg is bound up less in current sales and technology than in its promises of eco-repairs.[136] The eco-benefits of BioAg have less to do with what is currently possible than what is promised. Michael Fortun (2008) illustrates such promise in his ethnography of DeCODE Genetics, a public-private biomedical initiative. Companies like DeCODE, and an entire industry of gene-based medical therapies, can exist for years and accumulate capital on promise alone. Fortun shows how this industry, without even a flagship therapy to support its claims, is sustained by scientific studies, public press events and general societal interest. The AM inoculant industry, on the other hand, possesses what is to many farmers and gardeners a convincing product, and an incredibly efficient underlying industrial system of production (even if this system is limited to one species). Following the logic of biotech promise, the current state of mycorrhizal applications gives just enough evidence—to investors and the general public—that more sophisticated systems of production can realistically be constructed.

Amaranthus began producing and selling AM inoculants in the mid-1990s. In those "early days," he told me, he toiled through a lot of difficult PR work. This was a time when mycorrhiza was far from a household name, even among farmers and agronomists. In terms of explaining what the symbiosis is, let alone why a land manager should care about it, he had to start from the basics: "Farmers were not thinking about soil biology, at all… they did not know about symbiosis." By writing numerous articles for agricultural trade journals and for a general

---

[136] Even maintenance repairs (those that are not revolutionary, and merely strive to provide fertility amidst status quo industrial agricultural practice) have by and large been proven impossible to standardize, and any benefit in plant growth difficult to measure. This remains true even if some regional studies, such as those on potato production in Quebec, have shown positive results (Hijri 2016).

audience (e.g. the *Atlantic* article at the beginning of this chapter), Amaranthus played an active role in creating awareness for the symbiosis. Decades later, in 2019, a book featuring mycorrhizal symbiosis is even on the *New York Times* bestseller list (Wohlleben et al. 2016).

Mycorrhiza has taken on an incredibly green, "environmentalist" cachet. As promoted in how-to gardening books and books that elucidate and promote "alternative" agriculture, mycorrhiza is seen as an antidote to the shortcomings of industrial agriculture (or as a trope for eco-friendly soil practices, see Chapter 4). Thanks to this positive press, the biotech promise of AM inoculants has become a far easier sell.

This is the dominant vision among BioAg boosters. It is their sociotechnical imaginary in which inoculant technology will soon become sophisticated to the extent that inoculants can be created that are tailored to specific soils and crops. BioAg boosters have an imaginary of *personalized medicine for your soil*. This future of agriculture includes a (potentially) endless array of products, both prokaryotic and eukaryotic. It is an agricultural future that remains infused with the same sources and flows of capital that have been common in the industry for at least a half century. This is a future constrained by a rationale of accumulation by restoration; a future centered on and limited to products, and lots of them; a future in which only "win-wins" are permitted; and in which the economic gains go to status quo agricultural conglomerates.

What remains blurry in these visions of the future is the extent to which agricultural practice (rather than mere input substitution) must change. BioAg relies on the promise that its bio-technologies will become more sophisticated, and that these gains will enable *microbes to work* while retaining some of the twentieth-century technology that has brought time- and labor-savings to farmers (even if these savings in time and labor have merely been passed off to others, in non-agrarian industries and workspaces). This is textbook ecological modernization (win-win expectations), combined with a view of microbes as inherently hard-working (i.e. capital producing), as Stefan Helmreich (2008) found among groups of marine biotech researchers.

Symbio-capital

There is a deeper commonality between Linderman's *in vivo* products (and his regional claims) and the globally standardized aspirations of companies such as Premier Tech (and related researchers such as Fortin). Small- and industrial-scale inoculant producers, those who use *in vivo* or *in vitro* methods of production, and businesses that buy their inoculum from other businesses (and repackage it), all share a business strategy of separating chemical from bio-products, and adding further value with "symbio" marketing. This turning to symbio-value (or symbio-capital) has proven its worth. Fortin, who remains a scientific advisor on executive boards at Premier Tech, has told me how profitable mycorrhiza has been for the largely non-bio company. The challenge for any researcher in BioAg is how to simplify and homogenize—package—the complexity and context-dependency which is part and parcel to symbiotic functioning. That is, how to maintain the ethical and environmentalist *values* that the *symbio* has recently taken on while at the same time enhancing, controlling and economically exploiting these values (for multiple values, see Graeber 2001; Gudeman 2008). We might think of this tension in researching and promoting an inherently complex and context-dependent plant-microbe process, while also seeking to extract surplus value from it as a challenge in generating *symbio-capital*, a value-added version of biocapital that builds in industries that include biomedicine and environmental restoration.

In vitro and *in vivo* inoculants are often intended for disparate growers and contrasting soilscapes. But they share more common ground than not as projects of commodifying soil symbionts. Fortin and Linderman pursue differing strategies (with different ethics) to deal with the increasingly inescapable fact that twentieth-century industrial agriculture is an untenable system for twenty-first-century (Anthropocene) climates and concerns.

Even if Linderman has found exchange value precisely in those qualities thought to resist commodification (i.e. Castree's list), and has forged unorthodox ways (as described by the biocapital literature) to package, simplify, and standardize complex soil processes, he still creates commodified bio-objects (Vermeulen et al. 2012) that can be grouped with, or alongside, those sold by Monsanto.

CONCLUSION

What BioAg's Promised Future Precludes

The difficulties of AM inoculant commodification—an industrial system of production that only supports one species of AM fungi, which performs unpredictably across so-called homogenous industrial soils—beg the question: if not commercial inoculants, how else might mycorrhiza be included in industrial agriculture? Many researchers and farmers who do not subscribe to the BioAg approach also turn to mycorrhiza for enhanced plant production, without purchasing mass-produced inputs for their soils. Farming practices such as permaculture and biodynamics, and agricultural movements such as "no-till," are fully aware of AM fungal communities and direct their practices to the enhancement of AM fungi as well as the many other partner microbial and eukaryotic life forms. Rather than subscribing to practices begun with the industrial success of rhizobial inoculants, they instead focus on prescriptions—for example less tillage, continuous growing time (no fallow periods) and greater crop diversity (in space, multicropping; in time, crop-rotations). Compared to an affordable product with global application (and the promises of BioAg), these practices are far more laborious for farmers, may require the acquisition of new skills, and do not provide reliable economic wins for existent agricultural companies.

Just ten years ago, before large chemical companies began selling bio-fertility products, and before the popularization of *in vitro* inoculants, most inoculant companies sold their products regionally, and included recommendations for altering soil practices (beyond reduced phosphorus fertilization). Some smaller inoculant companies (e.g. Linderman's, but also those selling *in vitro* products) still sell their inoculants with the insistence that farmers alter their soil practices—primarily less tillage and more cover crops—so that broader microbial communities can thrive. By and large, inoculants are sold with less insistence on changed practice, though. It is increasingly accepted, even advised, that farmers use the inoculants and make no other changes to their industrial practices, save reductions in phosphorus fertilization. Inoculant sellers (and farm advisors) have told me that this is a "reality" when trying to sell bio-products to "conventional" (i.e. twentieth-century, industrial-minded) farmers. Such farmers do not want to hear about global environmental issues, these sales reps told me. First and foremost, they want to hear about economic savings. In some cases, after using the inoculants for a few seasons, farmers begin to notice that they can drastically cut back on fertilization; or their plants take on a healthier look and more robust growth. Fortin told me that this is important because it makes industrial farmers conscious of the role of symbiotic microbes. This is the start of building an awareness and appreciation for soil microbes that can be a gateway to greater agro-ecological considerations. Getting industrial farmers to think about plant fertility, beyond inorganic N-P-K sources, is an important step for sustainable agriculture in the future. As Amaranthus has noted, even Liebig reversed course toward the end of his life and advocated for the use of compost over inorganic fertilizers—thanks to its biological properties—for healthy systems of crop production (see Lowenfels 2015). Still, as I overwhelmingly heard during fieldwork, supplementing a handful of context-independent bio-fertility products for chemical ones is not the answer to sustainable agriculture in the future.

Researchers like Fortin and Amaranthus are key players in what Donna Haraway (2016) calls "staying with the trouble." They are aware of the shortcomings of industrial agriculture, including the difficulty of making necessary changes. But they have made careers out of staying with this trouble, not running from it to work with forms of land management that are more inclusive of their beloved soil symbionts (not to mention their ethics). On a few occasions, Fortin told me of his love for permaculture, while boasting that he works with such practitioners. But like Amaranthus, his passion and drive lie in confronting the industrial mode of agriculture that dominates the society in which he lives. When I spoke with Amaranthus about his peers and colleagues at Oregon State University and the USDA Forest Service, those doing fungal taxonomy or trying to better understand the role of mycorrhizae in "natural" ecosystems, he told me how he was always driven to "the practical issues." Instead of trying to sort out the evolutionary connections of species, he was motivated by questions of how to apply the benefits of mycorrhizal fungi to the vast acreage of industrial arable land that lies in the valleys beneath Oregon's forests. As is the case with Fortin, he did not consider it his job to completely overhaul status-quo agriculture (both insisted that their work has been separate from such a political undertaking). Rather, he spent decades confronting the practical challenge of making the complex symbiosis fit into a reductive agricultural system.

Should we laud the industrial pragmatism of researchers like Fortin and Amaranthus, and the broader framework of ecological modernization within which their work can be placed? We certainly cannot deny the short-term benefits that this approach has had; BioAg *does* hold the potential to significantly mitigate current eco-crises (Van Dooren 2014; Tsing et al. 2017). But as agro-ecologists such as Miguel Altieri point out, BioAg solutions only perpetuate the practices that got us into this problem in the first place. Promises aside, BioAg does not address the fundamental problems of industrial agriculture: the very logic of this system is inhospitable to sustainable and diverse agro-ecologies, which start with the myriad and interconnected lives of the soil. The accumulation by restoration framework directs our attention to the danger of only considering solutions with multiple wins; that is, inclusive of economic wins for status quo agricultural companies, such as BioAg provides. Limiting our purview to win-wins precludes the disruptive and inconvenient changes needed for the flourishing of greater human and nonhuman ecologies.

That is just one reading of BioAg. While it is true that BioAg may preclude some farmers from making greater change in agriculture—i.e. turning to amended practices and not just supplemental products—my purpose in pairing *in vivo* and *in vitro* production methods is to suggest that we think about each as being for different soilscapes and soil practitioners. While I have argued that BioAg and *in vitro* AM inoculants may do more to uphold than transform industrial agriculture, I have also tried to show that this agriculture cannot be wished away and that those who produce and promote *in vitro* inoculants have made a deliberate effort to connect with large-scale farmers, many of whom are "locked-in" to industrial practices due to government policy (e.g. subsidies tied to only a few commodity crops) and loans on heavy machinery. These farmers may not be able to use Linderman's holistic product (let alone follow no-till practices or initiate great crop rotations). BioAg just be the incremental change that they need, and may even be looking for. This is to say that context matters. Some soils are effectively clean of symbiotic microbes, in these cases affordable *in vitro* produced AM inoculants—even products limited to one strain of AM fungi—may bring the greatest growth response. In other cases, for example farmers with mid-sized farms who have more flexibility in changing agricultural practice may want to supplement their reformed practices with an *in vivo* produced inoculant that includes a greater array of microbes. In the next chapter I train my attention on spaces of inoculant use. I discuss a trend among mycorrhizal researchers and other practitioners who see those microbes that are already in arable soils (even if dormant or in subsoil layers) as a potential source of inoculation, an even more sustainable way to bring greater health of soil and plants.

CHAPTER 4: Achieving "Symbiotic Efficiencies": Experimental Settings and Arable Infrastructures in Dijon

In Chapter 3, I discussed the production of mycorrhizal inoculants used to boost plant production. I showed the desire to create a line of bio-products that are compatible with industrial agricultural infrastructure. With the turn of the twenty-first century, these products took on value as a foil to overused and environmentally damaging chemical products. I argued that boosters of biofertility inoculants promote the efficacy of "soil drugs" via a rationale that has industrial agricultural soils as *clean slates*, spaces in which soil symbionts no longer bring "ecosystem services" such as the translocation of water, soil nutrients and pathogen antagonism (Gianinazzi et al. 2010). With industrial soils flattened to a homogeneous space of *damaged* *second nature,* arable soils around the world—regardless of place and crop—are (discursively and materially) primed and ready for commercial inoculants.

Here I look further into the spaces in which inoculants are to be used. I introduce a contingent of mycorrhizal researchers who question the extent to which microbial communities fail to bring ecosystem services, or their inability to rebound on their own, without the use of commercial inoculants. Barring only extreme situations in which soils are extensively labored, these researchers argue that inoculants are not the best way to achieve what they call "symbiotic efficiencies." I forward the analytic of *arable infrastructure* to describe those soilscapes in which even these skeptical researchers argue that inoculants are likely to be effective. Arable infrastructures include the most heavily worked or damaged of agrarian soilscapes (i.e. those severely tilled and doused with chemical products); more so, the term encompasses an array of non-agrarian spaces that include sports stadiums and city greenways.

As spaces in which AM inoculants tend to be the most effective, some arable infrastructures double as experimental settings. Often situated in public spaces, these arable infrastructures provide new "real life" variables for experiments on how the mycorrhizal symbiosis acts not in sterile petri dishes (*in vitro*) or pot cultures in laboratories or greenhouses (*in vivo*), but in soilscapes that see high human traffic and manipulation (*in situ*). Arable infrastructures provide a window through which researchers can see how mycorrhizal fungi shape and are shaped by heavily managed terrestrial environments that will become more common in the twenty-first century. Often situated within public spaces, they also provide opportunities to expose broader publics to beneficial plant-microbe interactions.

In this chapter, I also show how arable infrastructures are networked. To researchers seeking data, inoculant companies seeking sales, and governmental and intergovernmental organizations seeking impactful environmental initiatives, arable infrastructures do not take on significant meaning as individual swaths of soil (which tend to be little more than a few hundred square meters large). Their worth to mycorrhizal research, governmental bureaucracy, and industry profits comes through arable infrastructures not as fragmented pieces of land, but as a networked category of the arable.

The worth of arable infrastructures relies on more than networked soilscapes. An equally critical component of the network includes the documentation that link the arable infrastructures, and gives them meaning to researchers, industrialists, elected officials, environmentalists and general publics. In this chapter, I turn to Dijon, France to describe arable infrastructures and the meaning that they have gained in the past decade as spaces ripe for manufactured symbiotic efficiencies (i.e. the use of AM inoculants, or what I will call consulting services that show how to enhance beneficial microbes). Dijon, as the capital of Burgundy, France, is a city with a rich history in research with AM fungi, and public initiatives to create green infrastructure. I describe an experiment conducted by researchers at the Agroecology Center that is part of the Dijon branch of France's National Institute for Agricultural Research (INRA). This is an inoculation experiment done in the grass beneath the city's newly installed tramway, a prime example of an arable infrastructure. This experiment doubles as a public display, an opportunity to teach Dijon residents and visitors about the mycorrhizal symbiosis and its potential applications. This tram experiment links with other public demonstrations/experiments with mycorrhizal fungi in Dijon, such as at the city's *Jardin de sciences*. These networked soilscapes have led to research documents that include a thesis for a Masters of Arts in Urban Landscape Management, scientific publications. These documents link with bureaucratic ones such as written for

European-Union-funded initiatives for biodiversity quantification,[137] and the "greening" of often resource intensive arable infrastructures in order to meet climate goals. These reports, which include the use of commercial inoculants, dovetail with those produced by agricultural companies that present findings from field trials that feature their inoculants. Also in the mix are media reports that describe these public experiments and the economic prospects of an emergent industry that sells biofertility inoculants. This serves the interests of companies who need to market their soil drugs, and of INRA researchers who as public servants have a mandate to perform public "outreach" of their science and prove the economic and environmental "impact" of their use of public (taxpayer) money (Cornu et al. 2018).

My focus on arable infrastructures helps clarify what boosters of AM inoculants ambiguously refer to as "sustainable land management," or "soil health." Returning to Christopher Henke's typology of repair, I argue that the use of inoculants in arable infrastructures is a form of "maintenance repair." Typically, this involves reduced irrigation and chemical fertilizer use in mono-cultured lawns, corporate park landscaping, or newly installed urban green ways. In these cases AM inoculants are not about enhancing biodiversity or creating agro-ecologies; they are instead about mitigating resource intensive forms of land management as they occur in highly constrained and labored soilscapes.

Analysis on the kind of repair offered by AM inoculants, in particular soilscapes, allows me to scrutinize how mycorrhizal researchers and industrialists use the concept of "sustainability." I argue that judgments of sustainability revolve around the optimization of a handful of ecosystem services brought by mycorrhizal fungi and the associated networks of

---

[137] For example, when I began fieldwork in Dijon Philippe Lemanceau, the director of INRA Dijon's Agroecology Lab, was the project coordinator of ecoFINDERS (Ecological Function and Biodiversity Indicators in European Soils). This was a Europe-wide initiative (that has since been completed) to create geographic soil maps that include biological factors of soil and not only chemical and physical properties.

plants, bacteria and fungi. "Sustainability," in this case, increases with the "symbiotic efficiency" of AM fungi. I argue that this notion of sustainability needs to be situated within (and qualified by) its broader context of soilscapes that even if made more "efficient" with AM inoculants remain resource intensive and reliant on fossil fuels. Indeed, arable infrastructures are major contributors to ecological destruction on global and local scales (see Robbins 2007).

Questions of sustainability aside, arable infrastructures (as experimental settings) contribute to mycorrhizal science in revealing how and when the plant-fungus association can bring symbiotic efficiencies. I position experimental settings beyond lab walls and agronomic field trials as part of a growing call within the mycorrhizal research community to, as one lead researcher put it, "work with mycorrhiza [as it exists] *in reality*." I interpret this as a push to think beyond how the symbiosis acts in a singular form, and instead ask how AM fungi act as part of complex groupings of fungi, bacteria and plants. This necessitates a departure from experimental systems based on one plant and one fungus, to those that include a cross-Kingdom assembly of species. I argue that mycorrhizal science is now going through a rapid multiplication of ever more complex versions of AMF experimental systems. Following Hans-Jorg Rheinberger's analysis, these systems provide glimpses of larger and larger "pieces of nature."[138]

Glimpses of larger pieces of mycorrhizal nature bring an ironic finding. The experimental systems and settings that have relied on inoculants increasingly show that commercial inoculants are limited in the symbiotic efficiencies that they can provide. Moreover, new findings that point to the incredible ecological plasticity of AM fungi—evidence that the fungi act in dramatically

---

[138] Rheinberger takes this reference from the autobiography of the famed microbiologist François Jacob. Rheinberger provides the following excerpt: "In analyzing a problem, the biologist is constrained to focus on a fragment of reality, on a piece of the universe which he arbitrarily isolates to define certain of its parameters. In biology, any study thus begins with the choice of a 'system.' On this choice depends the experimenter's freedom to manoeuvre, the nature of the questions he is free to ask, and even, often, the type of answer he can obtain" (Rheinberger 2012; 89-90).

different ways depending on who and what is around—make those singular inoculant experiments that were once the mainstay for demonstrating AM fungi's effect on plant growth seem disconnected from (if not irrelevant to) how the symbiosis acts *in reality*. This is akin to Linda Nash's (2006) description on how chemicals act differently in the laboratory (the context in which they are approved by governmental regulators for use) and in the "world;" that is, in agricultural fields. As researchers in Dijon explained to me, public demonstrations that feature AM fungi in a singular form reinforce over-optimistic views of the symbio-efficiencies that commercial inoculants can bring. This, I argue, has given rise to a division: On the one hand are the messages that come from public mycorrhizal demonstrations that are often in sync with the promises of inoculant companies; on the other hand are recent findings from mycorrhizal science that point to context specificity, if not the indeterminacies of microbial communities, whose functions in dynamic soil ecologies are always in flux and difficult to predict, let alone control. This new mycorrhizal science renders dubious the widespread use of AM inoculants.

How do these researchers skeptical of the use of AM inoculants propose to bring symbiotic efficiencies to agrarian soils? These researchers envision a future of (microbially led) agriculture not dominated by soil drugs but by an array of practices designed to enhance those microbial communities already in soils. Like the inoculant industry, what I call *symbio-consulting* is a sector that is part realized but mostly promised. S*ymbio-consulting* is a class of expertise that generates symbiotic efficiencies from reformed soil practices. This begins with the diagnostics of soil biology which then dictates prescriptions for nurturing those symbionts who will in turn give vigor to their plant hosts. From such cursory description, it would seem like symbio-consulting is indeed the best route to a future of more sustainable soil management. However, as I showed in Chapter 3 with *in vitro* and *in vivo* produced inoculants, symbio-consulting is more promising in some contexts than in others. More fundamentally, it is a technoscientific imaginary (even if it rejects one branch of technology in favor of practices that are often anything but "high-tech") whose effects remain to be seen.

Chapter Roadmap

I begin with historical context on an experiment run by researchers at France's National Institute for Agricultural Research (INRA) conducted on the grass planted along Dijon's new tramway, a commuter rail system in the city designed to reduce car congestion. I describe an experiment with AM inoculants at the tramway as an example of arable infrastructures: in this case one that is also an *experimental setting*, which I take to be a more spatially aware and expansive version of experimental systems.

The following section focuses on the scientific findings that have come out of the experimental systems and settings that are new to mycorrhizal science. This is a new wave of mycorrhizal research that draws from the results of the experiment conducted at the tramway, as well as findings from experiments conducted within the walls of the Agroecology center at INRA Dijon. I describe this new wave of mycorrhizal science as one in which researchers depart from singular views of the symbiosis (one plant and one fungus) to ask questions about how mycorrhizal *communities* interact with broader plant and bacterial communities (e.g. Martin et al. 2018). These findings are often at odds with how the researchers discuss their science to general publics in that they more clearly describe how much is *not known* about the mycorrhizal symbiosis; the findings also reinforce the opinion that commercial inoculants can only bring symbio-efficiencies to select soilscapes.

In the final section, I discuss *symbio-consultants,* a commodity form and form of expertise that is on the rise. Here, symbio-efficiencies are achieved by turning to more comprehensive soil management reform. This is not a rejection of soil drugs, but a shift away from their use toward reformed agricultural practice and an array of secondary technologies that directly consider soil symbionts (e.g. tilling regimes, planting schemes and crop breeding designed to encourage particular soil symbionts). Symbio-consulting now rises with the new wave in mycorrhizal science that looks at cross-Kingdom communities, and not singular mycorrhizal relationships; it is a response to the over-reliance on singular experimental systems (in mycorrhizal research), and the over-selling of commercial inoculants. The arguments made by symbio-consultants are part of an important critique (with solution) for how soil health can be achieved not just on small farms or among farmers who already follow soil practices considerate of soil symbionts. The very idea of turning to symbio-efficiencies as a way to sustainably manage soilscapes is a way forward for soil management that is neither an industrial model that ignores soil biology (or merely incorporates a soil drug into a broader regime of soil inputs), nor is it an "alternative" model that is not a viable option for farmers locked into farming vast acreage of only a select few commodity crops with heavy machinery.[139] The various prescriptions provided by symbio-consultants do not only provide a way for industrial farmers to meaningfully incorporate AM fungi (and their many associates) into their agro-ecologies; along with public mycorrhizal displays they help open a consciousness (or subjectivity) to the complexity of soil ecologies and how they are linked to existence and livelihoods of countless species—humans included.

---

[139] Farmers may be locked into this sort of farming due to government subsidies that are tied to certain crops or farm sizes, or due to loans on expensive machinery.

Mycorrhizal Practices and Multi-sited Fieldwork

With my jumping from Quebec to Oregon, and now to Dijon, France, a note on multi-sited fieldwork is in order. My discussion in Chapter 3 on the creation of systems to produce mycorrhizal inoculants required that I make a few geographical jumps (from Quebec and Oregon). Here in Chapter 4, I remain situated in Dijon, France, with a robust group of mycorrhizal researchers and others who work with plant-microbe interactions. Dijon has a rich history of such research, as it exists in public labs, environmentalist campaigns and private companies that work within the sector often called "biological agriculture" (or BioAg, the phrase that I use in Chapter 3). This chapter connects these mycorrhizal practitioners through arable infrastructures, soil drugs, and symbio-consulting. I describe experiments that lie at the vanguard of mycorrhizal science as well as those in public settings which, on the surface, are less about contributing to mycorrhizal science than "communicating" mycorrhizal science to broader publics (including scientific). My discussion on research carried out at a state-funded agricultural research institute (INRA) affords analysis on how AMF researchers position their work (and the symbiosis itself) as "sustainable," and how they tie mycorrhizal research to politically pressing topics and sectors such as the conservation of soil, the building of "smart green cities" (Clark and Cooke 2016), and the greening of industrial processes writ large (from agriculture to transportation).

PART I: Public Experiments and Arable Infrastructures

Dijon c'est ma nature! J'agis pour la biodiversité

I first heard this motto, *Dijon it's my nature! I act for biodiversity* in the summer of 2014. I was in this mid-sized town of just under 150,000 inhabitants (the nineteenth largest in France) for the summer while working with researchers at the Agroecology Lab at the Dijon branch of France's National Institute for Agricultural Research (INRA). As the capital of the famed wine region, Burgundy, Dijon is an affluent city with shops and white limestone plazas that have a decidedly upscale feel. Banners hanging above the pedestrian-only, cobblestone streets prominently display the motto that celebrates urban biodiversity. There were exhibits in parks, such as the *Jardin des Sciences* which featured apiaries, to teach residents about the ecological importance of pollinators. This public garden, which dates back to the 17th century and features plants both local and from around the world, had a temporary exhibit on mycorrhizal fungi. There was a row of commonly known plants that included the fungal-root symbiosis, and then another row of the same plants whose roots were not exposed to mycorrhizal fungi. The mycorrhized plants were larger and looked healthier than the others. Researchers call this an inoculation experiment. There was another inoculation experiment on public display in Dijon. Unlike the display at the public garden, which did not contain scientific merit, this one held the potential to say something meaningful and new to science about how AM fungi act in a public space, this one being a stretch of grass in front of the new Agroecology Lab at Dijon's INRA station. Also unlike the exhibit at the *Jardin des Sciences*, the tram experiment received heavy coverage in Dijon's newspapers and local television stations. In part this owed to the significance of the newly installed tramway, which was a proud symbol of green infrastructure for Dijon politicians and residents alike. This significance dovetailed with that of INRA's Agroecology Lab in Dijon, also newly constructed.

Green Infrastructures

In 2008, when the City of Dijon announced the construction of a new tram system, the news came as little surprise. The first national roundtable, *Le Grenelle de l'environnement*, had been held the previous year. *Le Grenelle* brought together leaders from the French energy and transportation sectors, environmental NGOs and research centers. Public figures and private corporations collaborated to forge a future in which France would be a global leader in green capital and infrastructure (*development durable*, according to terminology from the meeting).[140] Many of the more politically sensitive proposals—for example a nation-wide carbon tax increase—would have to wait until President Emmanuel Macron came into power. Less contentious projects, such as tramways in French urban centers, flourished. By 2014, twenty-eight French towns had newly built tramways and all were constructed with the goal of mitigating noise and carbon pollution by reducing the circulation of cars in city centers.[141]

The fact that researchers at an agricultural institute spearheaded a non-agricultural experiment (one about the growth of lawns, not crops) was not questioned in any of the media articles or by the Dijon residents with whom I spoke. This non-agricultural mandate for an agricultural institution is part of an often-told history of rampant industrialization that gave way to environmentalist alarm: Following the decimation of agrarian communities and landscapes in the two World Wars, France was pressured by the Bretton Woods Institutions to industrialize its agricultural system. At first, food aid by the tons and tractors by the hundreds were brought from the U.S. to France (Cornu et al. 2018). French leaders also realized the importance of developing

---

[140] Although this seems to have been a monumental step for environmentalism in France, there is no shortage of critics who argue that Sarkozy's "green" actions were largely him paying lip service to an environmentalist movement that he could not ignore. For example, critics say that Sarkozy's claims to cut "chemical use" in agriculture in half were vague to the point of being meaningless—they were never serious claims (Cornu et al. 2018).

[141] For more on how the tramways are publicly promoted, see http://letram-dijon.fr.

a national effort to bring science and technology to French agriculture. In 1946 French politicians voted to form INRA.[142] By the 1960s, France had transformed from a net importer to a net exporter of food. In 1969,Georges Pompidou was elected President of France. By this time he was already known for touting agriculture as *le petrole verte* of his beloved country, which may lack fossil fuel reserves but not the will to farm industrially. As the 1960s came to a close—with the continuing rise of crops increasingly linked to a burgeoning private agricultural sector—INRA found itself in an existential crisis. If the agricultural sector was strong and had ample avenues for further growth from private investment alone, what need was there for the publicly funded research institution?

The 1960s also saw the rise of environmentalism and the concomitant critique of industrial agriculture.[143] The American marine biologist Rachel Carson's influence reached the Francophone world in 1963 with the release of *Le printemps silencieux,* the translation of her classic book warning of the damage wrought by agricultural pesticides. Celebrated French writers including Rene Dumont and Jean Dorst, whose 1965 *Avant que nature meure* raised further awareness of the destruction caused by industrialization. A 1967 oil spill off the Brittany coast—121,000 tons of crude oil from the *Torrey Canyon*—further inflamed environmentalist sentiments. Whether on land or sea, such environmental catastrophes triggered demands that politicians initiate projects for the *amenagement* (restoration) of agrarian lands and for the "greening" of urban environments.

---

[142] INRA can be seen as an expansion of INA, the previous federal agricultural research center. However, INA only had offices and labs in Paris. INRA was formed with need to bring agricultural research to the country's agricultural regions (Cornu et al. 2018).

[143] Environmental histories that begin with Rachel Carson risk covering up earlier and kindred political efforts to improve occupational health that stretch back to nineteenth-century urban England (see Davies 2013; Nash 2006).

INRA leaders took notice. In the 1970s, they made environmentalism a pillar of the institute's research agenda, equal to agriculture and food safety. This environmentalist mandate brought renewed justification for research into "basic" biology (Cornu et al. 2018). By the 1980s, as the revolution in molecular biology—made possible by new tools for genetic analysis and the molecular-based recombination of life forms (see Rabinow 1996)—turned into a nascent and burgeoning form of biocapital (Helmreich 2009), INRA jumped on the bandwagon. INRA stations in Dijon and Toulouse developed research teams that focused on plant-microbe interactions. INRA Toulouse focused on agricultural applications with *Rhizobia*,[144] while the Dijon branch became known for work with AM fungi.[145] The millions of euros of federal funding that went into research with these microbes were justified to the French public with promises to mitigate environmental harm brought on by industrial agriculture.

This environmentalist mandate also allowed INRA researchers to look beyond agrarian soils or biodiversity found on farms. They could turn their attention to soilscapes such as the confined seventeen centimeters of soil that lay between the tram tracks that passed in front of their research laboratory.

A Surprising Finding

The tram experiment featured an array of different types of inoculants, used in varying combinations throughout the experimental site. The AM inoculants included *in vitro* produced

---

[144] Initial hoped-for applications with symbiotic microbes in agriculture concerned the optimization of nitrogen-fixing bacteria, namely *Rhizobia.* Currently, research groups at INRA Toulouse work with other public institutes such as CNRS to realize the Bill and Melinda Gates-funded dream of transforming non-leguminous crops to associate with Rhizobia. This could eliminate the need for nitrogen fertilizers altogether.

[145] Early mycorrhizologists such as Vivienne Gianinazzi-Pearson and Diederik van Tuinen were hired by INRA in the 1980s and 1990s to investigate how AM fungi might be employed to help make industrial agriculture more sustainable. Vivienne Gianinazzi-Pearson was the head of the unit that focused on AM fungi; she was then followed by Silvio Gianinazzi, who was succeeded by Daniel Wipf, who led the research unit during my fieldwork period (2014-2018).

Rhizophagus irregularis (as used commercially, see Chapter 3) and another AM fungal inoculum produced under *in vivo* conditions by the European Bank of Glomeromycota (BEG), which is located within the INRA Dijon Agroecology building. The bacterial inoculants included a commercial variety of plant-growth promoting rhizobacteria (PGPR) called *Pseudomonas fluorescens*, and bacterial strains that researchers collected from soils around the experimental site, including from the campus of the University of Burgundy, which is adjacent to the INRA Agroecology Lab. Researchers sent these soil samples to Agronutrition, a company that produces biofertility inoculants. Employees with Agronutrition identified, isolated and cultured beneficial bacteria to the quantity needed in the experiment. INRA researchers named these local strains "campus bacteria." These various inoculants were applied in differing combinations, so as to compare how the various inoculants (locally adapted or not; fungal or bacterial) impacted plant growth.

INRA researchers found that even in the seemingly confined soil between the tram tracks, regional soil microbes, compared to commercially-available inoculants, played an outsized role in plant health. Wipf explained to a newspaper reporter that a surprising finding of the experiment was that by various measures the "campus bacteria" performed better than the other inoculants. The confines of the tramway—essentially a few-inch deep trough that rests on gravel and asphalt and is bordered by rails and a cement sidewalks—did not preclude regional microbial communities from altering the effects of the inoculants, either by outcompeting the introduced microbes or otherwise inhibiting them from bringing the desired effects.

Although the tram experiment showed that inoculants can aid the growth of plants in such confined soilscapes, it also demonstrated the need for inoculants designed for specific soil types, in specific locales.[146] The tram experiment showed how exceedingly rare it is for any soilscape to lack microbial communities that make the efficacy of AM inoculants dubious. This does not discredit but greatly limits the use of commercial AM inoculants.

That regional microbial communities play a significant influence, even in confined soil brought in from afar, was not a groundbreaking finding for mycorrhizal science. For over a century, researchers have been trying to keep microbes out of certain swaths of soil so as to run "clean" inoculation experiments. Especially for larger field trials, this is no easy task. Even if fumigated with chemicals or baked with plastic covers, dormant microbes regrow or propagules soon blow in.

Public Outreach Success

As a form of public outreach for mycorrhizal researchers at INRA, the tram experiment was very successful. The launch of the experiment alone was a substantial and spectacular undertaking, one tailor-made for a splashy news story. The *coulee verte*, or greenway that spatially makes up the experiment, is 45 meters long and 6 meters wide. Minus the space for the tram tracks themselves, the experiment consists of 132 square meters of soil, planted with a variety of grasses and micro-clover. This swath of soil, which had been planted with grass when the tramway was first installed a few years prior, would have to be torn out with backhoes. But the heavy machinery could not be brought in until after the final tram of the day had passed at around 12:30am. At that hour, with flood lights in action, over a dozen researchers donning *gilets*

---

[146] A commercial market for regional inoculants is still in its infancy. Companies such as Agronutrition, who created the inoculants for the tram experiment, are the exception. Many inoculant companies advertise regionally specific inoculants, or those tailored to specific soils. However, as many researchers told me, they doubt how "local" are these inoculant mixes. Most, the sceptical researchers suspect, are comprised of AMF isolates whose provenance are not precisely known; the local claims come as species are mixed together which have been found to proliferate in certain soil types and regions.

jaunes (yellow safety vests) got to work in the experimental space. Once the upper layer of the existing soil was removed and replaced with new soil, the experimental space was partitioned off into 120 roughly 1.25 square-meter parcels. Each parcel would get a specific combination of inoculants and seed. Researchers then systematically added the specific combination of inocula and grass or microclover seed into each rectangular parcel of soil.

Images of typically lab-based researchers working in the middle of the night on the construction zone made for great photojournalism that attracted public attention to the existence and contributions of beneficial microbes which otherwise would have remained invisible underground. As administrators at INRA proudly showed me via printouts bounded in a folder, over a dozen television and newspaper pieces had covered the experiment. This public experiment helped INRA researchers justify—in economic and environmentalist terms—why they had been laboring with mycorrhiza for decades in the lab. The tram experiment showed how AM fungi could be put to work in making the tramway *doubly green*: if optimized, beneficial plant-microbe interactions would reduce the need for irrigation, fertilization and mowing; mycorrhiza would bring a second layer of "green" to an already green infrastructural project.

As one INRA researcher told me, as a "public servant" he has a duty to devote a certain amount of time to "public outreach." He, like other INRA researchers, must also explain the economic impacts (potential and realized) of his work. I saw both of these tasks avidly taken up by Daniel Wipf, who leads a team of mycorrhizologists at INRA Dijon. Wipf was also the media figurehead for the tram experiment. As he and his colleagues wrote in a white paper, new *coulées vertes,* or greenways such as at the tramway, are ideal settings in which to showcase the importance and potential applications of the mycorrhizal symbiosis. These are spaces frequented, daily, by large numbers of residents who may have had no exposure to agrarian lands or even to personal gardens—spaces within which the mycorrhizal symbiosis is usually discussed (if discussed at all).

The tram experiment continued on after my fieldwork period, with researchers sampling the soil biology and planting more microclover. Wipf and others continue to promote the experiment, for instance during the annual *La Nuit Européenne des Chercheur.e.s* (held across Europe). For this event Wipf would ride the tram as it made its stops, all while teaching mycorrhizal biology to commuters. A media account tells of Wipf on the tram explaining how proper mycorrhizal connections in the soil beneath the tram tracks could help the city reduce the amount of irrigation and chemical inputs required to maintain the grass. He explained that an industry is now building around products that can be bought commercially and used to "inoculate" such soilscapes. Aware that there are not enough urban greenways to support an entire industry of mycorrhizal inoculants, I frequently heard Wipf (along with other INRA researchers) name other soilscapes that could benefit from microbial inoculants. One such space, which Wipf has mentioned in a few media interviews, are ball parks. In one interview Wipf linked AM fungi to the globally adored Brazilian football (soccer) star Neymar. Noting how football players already complain that the grass is too slippery, and that AM inoculants can help reduce the need for irrigation, he rhetorically asked the reporter: "Can you imagine Neymar hurting himself while playing at the stadium in Dijon? (Dissoubray 2018).

Neymar is one of the most charismatic football stars in the world. The mental image of Neymar benefiting from the "ecosystem services" of mycorrhizal fungi is a way to bring charisma to a group of fungi that score low in what Jamie Lorimer (2007), in the context of environmental conservation, calls nonhuman charisma. More important is how Wipf directs public attention to the many soilscapes that have been built from scratch, for instance sporting arenas, golf courses, and suburban lawns or corporate parks. Land whose management would be made less resource intensive with AM inoculants. Think of all the lawns that are continually restructured, overhauled, grown on soil that may have been fumigated and was likely treated with chemicals. These are not spaces for biodiversity preservation, but spaces that particular societies hold up to high aesthetic standards of orderly green. Regular overhaul of soil and grass is often needed to maintain this verdant perfection. As with the tram tracks that rest on asphalt, or a golf course built in the desert, these are *new* soilscapes in that they lack the geological and biological histories of agrarian, prairie or forested soilscapes, as soil trucked in from far away they will mix with their new environment in unexpected ways (Rillig et al. 2016). I turn now to consider these spaces as *arable infrastructures*, a category which I take to include not only public green spaces, but also an increasing number of experimental plots that now multiply with the popularization of mycorrhizal science. I found that those researchers who are critical of the use of commercial inoculants in most agrarian settings (they either see inoculants as ineffectual, or as a band-aid fix that doesn't address the underlying issue of why the microbes are not doing their jobs in the first place) were willing to promote inoculants in arable infrastructures.

All of the researchers with whom I spoke in Dijon had at least a few soilscapes in which they thought that inoculants could be effective. In some cases this was limited to experimental field trials, nurseries and sports stadiums. In having these discussions, I soon came to see that these researchers were well aware that public funding for their work in plant-microbe interactions, which may have nothing to do with the inoculation of economically important plants, was connected with the success of the commercial inoculant industry. Since INRA took on basic research with its mandate to address environmental issues, not all researchers are required to conduct research that links directly to agricultural applications. However, they must demonstrate some degree of "impact," and make an argument for the economic, social or environmental (potential) of their work. This is where it becomes important that arable infrastructures are linked with a network of paperwork that includes reports for European Union climate goals and annual industry reviews for the French government (on the role of paperwork in bureaucracy, see Hull 2012). Inoculants as used in arable infrastructures, help make the economic and environmental potential of AM fungi (and mycorrhizal research) legible to governmental bureaucracy and of interest to general publics. This occurs as a symbiosis typically hidden underground becomes visible through a packaged commodity and displays that pair mycorrhized with non-mycorrhized plants, with the former appearing larger and healthier than the latter.

Arable Infrastructures

My engagement with infrastructure is part of a scholarly movement in which the term is construed far beyond how "people commonly envision infrastructure as a system of substrates—railroad lines, pipes and plumbing, electrical power plants and wires" (Star 1999; 380). Geoffrey Bowker and Susan Star (1999) broadened the discussion by including discursive classifications and ordering systems as necessary components of material infrastructures; Bowker and colleagues (2010) built onto this work with what they called knowledge infrastructures, a focus on the ideas and ideologies that flow with materials. Far from a "call to study boring things" (Star 1999; 377), a literature in the social sciences and humanities has become quite lively. Scholars such as Casper Bruun Jensen (2015) and Peter Taber (2017) have written about "environmental infrastructure," pulling prior research into the fold, for example histories and ethnographies in which human engineering and natural processes shape one another on the

Columbia river (White 1996) and an Amazonian tributary (Raffles 2002). This is further proof that the modernist project of "purifying" any sense of the cultural in the natural (and vice versa) has never succeeded (Latour and Porter 1993). Extending out of this conversation Stefan Helmreich (2016), in analyzing the engineering of waves and wavescapes, has forwarded the concept of *infranature*, which he uses to keep sight of the natural—an idea that remains important to researchers, engineers and politicians—while calling attention to the cultural and material reworkings of nature. Instead of seeing an unmediated nature superseded by a built one, Helmreich describes built environments as "recursively folded back into" (*ibid.* 84) a nature unmediated by humans. In this way, Helmreich can show how a "natural" phenomenon in a "natural" space (waves in the ocean) nonetheless take on meaning in culturally specific ways; I maintain that we can look at arable soils similarly.

Mycelium that connects the roots of multiple plants and uses chemical signals to initiate the transport of minerals and water between plants, fungi and bacteria matches a popular imagery in which infrastructure consists of metal pipes and transit hubs. Such fungal connections also fit descriptions of organic nature and built environments recursively folding onto each other. Arable infrastructure incorporates this meaning while also highlighting the design, construction and regular maintenance (and decay and disrepair) that goes into the making of certain soilscapes. Infrastructure, as Nikhil Anand and colleagues (2018) argue, is inescapably about envisioning and promising particular futures, and then attempting to reify these futures in material form. Thinking with sponges and aquifers, Andrea Ballestero (2016) discusses how infrastructures are thought in functionalist terms, and how the limits of infrastructures—what they are deemed as able to do—depend on time and place. Infrastructures shape and are shaped by what Donna Haraway (1997) would call the shifting "material-semiotics" of a society—this is to point out not just the networked materiality, but the networks of meaning that connect with materials and non-materials (discourse, symbolism, ideology). In his anthropological review of the concept of infrastructure, Brian Larkin (2013) points to an array of ethnographies that similarly show that material and semiotic significance are always intertwined and co-produce each other. In some cases, the materiality of the infrastructure is at odds with its political and symbolic significance. In their widely-read essay "When is a Pipe not a Pipe," Tess Lea and Paul Pholeros (2010) show how piping in a house built for aboriginals has many material and representational meanings. The pipes, it turns out, do not actually connect rooms in the house to the neighborhood sewer system, but they do provide "aesthetic order" and they allow governmental and non-governmental reports to be written and money to flow. Skeptics of the AM inoculant industry likewise see a false connection between introducing manufactured AM inoculants to soils and any kind of repair to soil ecology, let alone significant and consistent responses in plant growth.

In part owing to the difficulty of knowing whether the specific effects of AM inoculants after they are applied, inoculant companies have been able to build consumer confidence by extrapolating from decades' worth of studies that demonstrate various symbiotic efficiencies, even if these studies bear little resemblance to the soils in which the inoculant will be used. Inoculant companies also link with government-funded reports on the importance of microbial diversity for agro-ecological health (e.g. ecoFINDERS). In this way, two material forms—paperwork (governmental and scientific reports) and earth (microbes and minerals)—come together to define arable infrastructures.

Infrastructures also reify the political-economic, material and epistemic conditions that determine what futures a society can imagine. In the introduction to the edited volume *The Promise of Infrastructure*, Nikhil Anand, Akhil Gupta and Hannah Appel (2018) similarly write of material networks—pipes, roads, electrical conduits—that do not only transport resources or things but also support political agendas and build layered temporalities that shape who and what is included or not in those networks. As they point out, soil has been formed, if not constructed, ever since it was ploughed and irrigated some ten thousand years ago.[147] Across the Global North, agriculture went through a rapid phase of industrialization. This occurred in the wake of World War II as war-time technologies were brought to civilian sectors (Light 2003). As many different facets of farming became mechanized—tilling soil, planting seeds, applying fertilizers and pesticides, irrigation, harvesting, could all be done with machines (see Fitzgerald 2003)—and chemicals to fumigate and fertilize crops became cheap, agrarian soilscapes could increasingly be described as materially engineered. This mechanization and engineering of arable spaces supported a narrative in which technological progress is linear, and so too is human control over nature's workings (see, Borlaug 1971; Conway 1997). But such notions of progress relied on ignoring or bracketing environmental impacts such as the "downstream" impacts of high concentrations of chemicals and minerals (Shiva 1993), and the negative health impacts of chemicals on those who help produce and then consume the food (Nash 2006). Such bracketing of environmental limitations or ills became institutionalized through terms such as "externalities," as used by economists.

I broadly construe the term *arable* to reach beyond agrarian contexts, to include any soil that is regularly worked or labored within. To make arable is to *labor* within a soilscape.[148] Regular tillage contrasts arable land from pasture land. The non-agrarian soils that I describe as arable are even more heavily labored than most agrarian soils. Ballparks and golf courses are

---

[147] The date of soil forming and construction can be extended back much further, to practices in South America that have left subterranean bands of carbon-rich soil called *terra preta* (see Churchman and Landa 2014).

[148] For the etymology of arable and its relation to labor, see OED (2019).

regularly reworked by physical disturbances and chemical alterations; plants (grass, typically) and upper soil layers are regularly overhauled or replaced. It is this disturbance, this labor, that I index with the word *arable.*

I combine arable with *infrastructure*—rather than *land*—to evoke images of soils confined by concrete, sandy bottoms (think verdant golf courses in the desert) or buildings and infrastructure such as sewer systems and tram tracks. I use the term infrastructure (and not land) to highlight the diminished role of geological timescapes and biological successions. These factors are central to the work of farmers and foresters, but less so to managers of ballparks and urban greenways which are often built atop subways and parking garages. Arable infrastructures have various degrees of separation from such terrestrial features.

In some ways arable infrastructure is a new name for non-agrarian soilscapes and political ecologies that other scholars have already pursued. Notably, Paul Robbins (2007) has written on the political ecology of the suburban lawn. Robbins discusses "lawn people" as those who liberally use chemicals and physical disruption (even regular lawn replacement in the form of sod) to ensure orderly green. Robbins' point is that the construction and maintenance of these infrastructures is deeply unsustainable. Compared to critiques of industrial agriculture, the actions of lawn people are often under-discussed, yet a significant environmental issue.

Seeing is Believing: Mycorrhizal Singularity

Dijon's biodiversity campaign included two displays with mycorrhizal fungi. The second, at the *Jardin des sciences* was a display solely for pedagogy[149] and to create public awareness of the

---

[149] The Jardin experiment was also a teaching opportunity for graduate students. It fulfilled the requirements for a student who earned a master's degree in urban landscape management (*GESTION DU PATRIMOINE PAYSAGER VEGETAL EN MILIEU URBANISE*).

symbiosis. With the goal of generating awareness and concern for mycorrhiza, the exhibit in Dijon's public garden followed a format that has been around since the early twentieth century when mycorrhizal researchers had to convince a skeptical scientific community of the eco-physiology of the symbiosis. The display brought to life what are typically photographs of big plants (inoculated) next to little plant (not-inoculated) in scientific reports, trade magazines and inoculant company websites. Included in the display were two rows of economically important plants (agricultural crops and domesticated grasses). Each species was planted side-by-side, in separate soil beds, for easy visual comparison. All the soil was fumigated, but only one row was inoculated with AM fungi. This enabled the Dijon public to see for themselves that the inoculated plants grew more vigorously; it was a simple and straightforward way for Dijon residents to comprehend the microbial diversity that lay beneath their feet. As Steven Shapin and Simon Schaffer (2011) describe in their account of Robert Boyle's public experiments with his air pump, "seeing is believing." The display in Dijon's public *jardin* brought into sharp relief for those on a Sunday stroll abstract claims about plant-microbe interactions that now litter popular science and gardening magazines.

Although displays such as the one in the *Jardin des Sciences* is an effective way to make an invisible symbiosis visible, it is based on a simplistic logic of mycorrhizal fungi that are either present or absent. This is a reductive experimental design that deals not with communities of plants and microbes but rather with *mycorrhizal singularity*. Presence/absence inoculation experiments result in what one researcher derisively called "big-plant-little-plant" photos: pairings of little plants that lack AM fungi with larger plants that have a healthy mycorrhizal connection. They are ubiquitous in the mycorrhizal literature, and in publicity material for the inoculant industry. They are an effective way to bring awareness to what AM fungi have been busy doing belowground for millennia. But this is not just the observation of natural processes. Public demonstrations—at either the tramway or the *Jardin des Sciences*—are also designed to promote mycorrhizal applications, the manufacture and management of AM fungi in laboratories and arable infrastructures. This is a nature-culture entanglement: an attempt to make the management of soil symbionts whose work had previously been taken for granted not just visible, but a matter of concern (Latour 2004). This making visible of what had previously been working, unseen and unknown, belowground, is an example of what Geoffrey Bowker (1994) has called "infrastructural inversion"—that is, an attempt to convert a plant-fungal network into a technology that will then be folded back into organic nature, and finally brought to the attention of society via boasts of spectacular engineering, with added economic value and politico-environmental values to boot. This is an attempt to naturalize inoculant technology.[150] This is more than the making audible of the quiet "hum" of infrastructures (Hetherington 2019), but a claim that inoculant technologies, in a sense, have always been around, only now they are available via global supply chains, and in an optimized form.

But what, exactly, do these experimental settings with mycorrhiza prove? Do they reveal what AM inoculants will do if applied to a garden or agricultural field? Critics say that such experiments merely show what the mycorrhizal symbiosis is capable of doing; they do not indicate how inoculants will impact plant growth in a particular setting—not unless one is dealing with soils *clean* of microbial communities. But as INRA researchers discovered, even the soil between the tram tracks does not hold such cleanliness: despite being trucked in and kept

---

[150] However, not all agree on the degree to which this inversion is so clean-cut or natural. As we saw in Chapter 3, inoculant boosters declare that many soilscapes have long been without their symbiotic connections, or that these connections are woefully un-optimized for industrial arable soils. If this is the case, the inoculant industry does not only bring long-standing underground processes into economic and political sight, but creates new infrastructures of soil symbioints.

separate from nearby soil, it was still filled with microbial communities strong enough to render the effectiveness of AM inoculants dubious. As Wipf explained to a reporter, the persistent influence of local microbial communities, even in a soilscape as sequestered as the trough between the tram tracks, was one of the more enlightening findings from the tram experiment. However, this finding was not what Thomas Kuhn would call an "anomaly." It is rather a puzzle piece that fits into an emergent framework of mycorrhizal research that is carried out within the walls of INRA Dijon's Agroecology lab: one that does not look at mycorrhiza as a singular connection between one plant and one fungus, and instead experiments with *communities* of AM fungi, plants and bacteria.

PART II: A New Wave of Mycorrhizal Research

The Plasticity of Experimental Systems

Within the walls of INRA Dijon's Agroecology Lab a wide array of experiments with AM fungi take place. There are the traditional plants in pots, with various soil and soilless media, which are able to nurture a wide array of AMF species. These *in vivo* "pot cultures" are grown in windowless grow chambers or in a greenhouse a short walk from the agroecology building. After the plants have grown to the required age or size they are brought to another room where they will be measured and observed. Measurements may involve identifying AMF species, counting spores, mycorrhized roots, etc. To conduct these measurements researchers separate the "aboveground" portion of plants from their "belowground" portion. The aboveground portion is measured and the plant mass is weighed. The roots are carefully washed with variously sized mesh used to catch root fragments or spores of known sizes. To visualize hyphae under the microscope a blue stain is used on the roots.

In contrast to such *in vivo* methods there are also fully sterile (*in vitro*) systems in which one fungus (*R. irregularis*) is grown on a root organ culture of a model plant species (e.g. carrot plants).[151] Most experimentation, however, lies somewhere between the two poles. After a few weeks in the INRA lab I realized that experimental systems are anything but static; rather, new versions, additions, subtractions and combinations seem to come with every new experiment. Researchers tweak experimental systems (or completely re-engineer them) depending on the research questions pursued. The trend in the research community is to adjust experimental systems so they are able to facilitate questions that ask beyond how one plant interacts with one fungus. For instance, one experiment featured three grass species, and a few bacterial groupings, species that are common to grasslands in France. This experiment was led by Pierre-Emmanuel Courty, a researcher who specializes in creating complex lab-based experimental systems that come a few steps closer to resembling environments in which AM fungi dwell, beyond arable infrastructures.

When I began my fieldwork in Dijon, Courty was not yet a full-time employee at INRA. He split his time between laboratories in Switzerland and France. This required that Courty transport his personally designed and bulky experimental systems between the two locations. I got an idea of how this played out one Friday morning, when I had arranged to arrive at the lab earlier than normal to meet Courty who was driving in from Switzerland. I waited with another

---

[151] What I call singular in vitro systems, which concern one fungus and one plant, remain important to mycorrhizal science. In one sense they serve as a baseline to which other variables are added. They are a reductive methodology referred to in the scientific literature as a "single-variable approach." These systems are critical for witnessing how an AM fungus grows before it meets its host; the chemical signaling used to find a plant host; initial hyphae/root connections; mechanisms for the transport of carbon and soil minerals across plant root and fungal hyphae, etc.

researcher who would participate in the research. Courty arrived later than expected and in a hurry. He jumped out of a hatch-back car filled to the brim with piles of plastic containers, pieces of PVC piping, sockets, mesh, and other materials that seemed more appropriate to an engineer than a biologist. These materials would replicate an agricultural field in which sorghum is grown alongside alfalfa and other legumes; the goal of the experiment was to see how various bacterial and AMF species interact in these environments. We had two large dollies ready to go and we unpacked the random pieces, some of which were still connected in configurations for the previous experiment. Everything went to the basement of the agroecology lab, where the experiment would take place.

We spent the first few days connecting piping and closing off boxes, and installing mesh of various densities that would prevent and allow roots and fungal hyphae from entering different chambers. There was quite a lot of off-the-cuff cutting of tubes and adjusting of screens. Here was experimental system as scientific infrastructure. Courty handled all of these improvised fixes with ease. As the day wore on, and small repairs and adjustments became the norm, the necessity of Courty's engineering aptitude became apparent. He modestly explained that years of trial and error (messy and filled with error) went into this skill. But it was clear that he had a knack for such construction. Others in the lab who have worked with Courty for years attested to his skill. Figure X shows the various chambers in one experimental system that he designed. Each chamber serves as a replicate, to test different combinations of plant species that either serve as host to one type of AM fungus, multiple species of AM fungi, and then fungi with and without introduced beneficial bacteria.

Once such systems are constructed they often go in rooms in which light, air temperature and moisture can be controlled. At INRA Dijon, many such grow chambers were behind thick, insulated doors that are like walk-in coolers in an industrial kitchen. Even with artificial, high-end "full-spectrum" lighting and well-established methods to water and feed plants, researchers still often had to go through a few rounds of getting the various sorts of seedlings to germinate in unison. Of the few experiments that I observed or participated in at INRA Dijon, these plant species included leguminous plants such as varieties of pea and the model species *Medicago truncatula*, which were frequently paired with a grass, such as maize, sorghum or bahiagrass. Experiments with AM fungi and grapevines were also common (given the importance of the crop in the region).

Such experimental systems are not designed to answer research questions about the physiology of one model AM fungus as it meets one model plant. Research questions shift from the physiology of the model AMF species, *Rhizophagus irregularis* (plus requisite plant host), to how this particular AM fungus interacts with other fungi, bacteria and plant communities. To answer such research questions sterile (*in vitro*) conditions become less common. This is not a return to the indeterminacy of open pot experiments, but a calculated adding back in of non-sterile (*in vivo*) factors. Although not fully sterile, such experimentation still requires nuanced and tricky procedures of sterilizing seeds and then germinating them in sterile conditions. These plants are then placed in an array of media, perhaps sterilized and soilless mixtures or soils filled with unknown microbial communities.

Courty and others involved with the design and construction of such systems are fully aware of the trade offs that come with these less sterile experimental systems, which add in layers of variables, some of which cannot be measured. It is easy for researchers who still adhere to simplified *in vitro* experimental designs to critique such complex systems—with the added uncertainty that comes with the interactions of layers of organisms, and with uncontrollable (*in* *vivo*) variables—as faulty or as lacking scientific rigor.[152] But, with researchers such as Courty who now find that AM fungi act with surprising diversity depending on such layered factors, these complex (if less controlled) experimental systems also hold greater promise for exciting new findings (ample *jeu de possibles*; see Rheinberger 2012).

With the ability to engineer mini infrastructures that house multiple strains of plant and microbe—connecting some with others, at specified times—those with engineering skills (such as Courty) hold an increasingly important position in the community of mycorrhizal researchers. If nothing else, these complex experimental infrastructures show that AM fungi have incredible variability and plasticity. But this finding need not come from experimental systems that are innovative or complex in their design. Experimental systems can also be tweaked in the most subtle of ways. For example, another experiment at INRA Dijon merely adjusted for different densities of host plants, in order to see how one strain of AM fungi would react. With only this one very basic variable at play—differing concentrations of one host plant—an AM fungus (all on its own) exhibited surprisingly contrasting behavior (Derelle et al. 2015).

At a very basic level this shows how much is *not* known about AM fungi, even as they act in the most simplified contexts of laboratories and formal experimental settings. But even as these findings point to seemingly endless variance in how AM fungi act depending on context, for some researchers they carry clear implications for how and when AM fungi are able to provide "ecosystem services" such as nutrient transfer, pathogen suppression and improved soil structure (Gianinazzi et al. 2010). One INRA researcher explained the use of symbiotic microbes in making agriculture more "sustainable" as a matter of achieving "symbiotic efficiencies," by this he meant the extent to which AM fungi are able to bring these ecosystem services.

---

[152] How to account for so many variables, and then pair such research with the clean and more determinate findings that come from sterile labs has long been an issue for ecologists who conduct research "in the field" (Kohler 2002).

Sustainability and Symbiotic Efficiencies

Experimental settings and in-lab systems, which now consider AM fungi as part of broader communities of plants, bacteria and other fungi show that achieving symbiotic efficiencies is anything but a straightforward process of applying one strain of AM fungi (which comprises most commercial inoculants). The tram experiment showed that even in such a (seemingly) sequestered setting, still local ecologies of soil microbes impacted the extent to which commercially available inoculants could bring promised responses in plant growth. The takeaway for many at INRA Dijon was that commercial AM inoculants are useless, but that their use is greatly limited to only the most artificial of soilscapes (soil heavily treated and labored).

More than limiting the prescription of inoculants, such conversations with researchers provided a window into what exactly is meant by claims that AM inoculants can bring more "sustainable" land management. In sports stadiums and urban greenways built atop parking garages—spaces with a narrow layer of trucked in and heavily managed soil—the use of a single strain of AM fungi may very well allow less frequent watering and fertilizer use. This, on its own, is a notable achievement in making land management more green or sustainable. But should we not have a different measure of sustainability for less manufactured soilscapes, those with multiple layers of soil, subsoil, bedrock, with concomitant geological and biological temporalities? In such soilscapes should "sustainability" not move beyond mere efficiencies in resource use to include more lasting improvements in soil health? The efficacy of AM inoculants becomes more dubious with claims that reach beyond a product that supplements chemical forms of fertilization— claims that inoculants can bring greater ecosystem services such as improved soil health. Not surprisingly, when mycorrhizal researchers argue for the (potential) "impacts" of their work, or when representatives of inoculant companies proclaim the benefits of their product, they often turn to a definition of sustainability that moves beyond input substitution (biofertilization) to a long list of "symbiotic efficiencies," which have accumulated with decades worth of research with AM fungi.[153] The problem is that these studies show what the symbiosis is capable of doing—largely in controlled laboratory settings or non-agrarian soils.[154] They do not reflect what commercial inoculants are capable of doing, in the majority of agrarian soilscapes.

I frequently heard and read discourse of "services" (ecosystem) and "efficiency" (symbiotic) during fieldwork with AM researchers and industrialists. Researchers made no claims of not holding what Maria de la Bellacasa has (2015) called a "producitivist" stance to soil symbionts, a perception in which nature is something for human use, what Neil Evernden (1985) has called "resourcism." All AM researchers take seriously the critical role that AM fungi play in the health of plants, especially those that humans, writ large, depend on. Rather than having any ethical quandary with an instrumentalist view of nature (as opposed to centering one's attention on "inherent" qualities of nature [see, Kloor 2015]), they hold strong ethical commitments to learning more about AM fungi so as to ensure that the symbiosis is best *used* for human ends. Through this lens, actions of AM fungi such as the translocation of phosphorus, the

---

[153] In the early twentieth century, benefits centered on phosphorus uptake from one fungus to one plant. As the century progressed more nutrients were added to the list, along with the transport of water. AM fungi's ability to house bacteria that are antagonistic to plant pathogens is now widely accepted in the research community, and so too is AM fungi's role in improving soil structure (via the exudate glomalin). For more, and a general discussion of the mycorrhizosphere, see Chapter 3.

[154] See, especially, the last sentence of this excerpt from a paper co-authored by a leading AMF researcher, Ian Sanders (Ceballos et al. 2013): "One major importance of this study is that we used the fungus *R. irregularis*. This species has become the model AMF studied by molecular biologists because, unlike many other AMF species, it can be efficiently produced in vitro. Also, the genome of this fungus has now been sequenced (F. Martin, personal communication). Thus, laboratory-based studies on this species, have rendered much of the knowledge we have about AM fungi."

suppression of soil pathogens and the agglomeration of soil become "efficiencies" that can improve agricultural practice by cutting back on the need for resource intensive products (fertilizers, pesticides) and practices (regular inversion tilling), all while building even greater soil microbial communities, those that remain unknown to researchers. We might think of "ecosystem services" as a term that encompasses more of the overall agro-ecology, or at least as a term that is more inline with the philosophy and practice of "agro-ecologists" (see, Altieri and Farrell 2018). Coming from the lips of mycorrhizal researchers, I heard the two terms used interchangeably.

With the latest mycorrhizal science casting an ominous cloud over the ability of one (or even a few) industrially produced species of AM inoculants to bring symbiotic efficiencies that reach beyond short-term plant fertilization, what will become of the multi-million dollar industry that researchers use to justify the economic impacts of their work? Is it unrealistic to think that robust AM fungal communities that bring greater symbiotic efficiencies can exist in industrial agriculture? I did not meet a researcher who held such pessimism. In the words of one researcher, to view industrial agriculture and thriving AMF communities as incompatible would be the equivalent of "throwing the baby out with the bathwater."

Some researchers still argue for a future with a greater array of inoculants, which are attuned to specific soil types and local ecologies. But a large contingent of mycorrhizal researchers (based on those with whom I spoke in Dijon, and beyond) argue that such a focus on inoculants does not address the underlying issue; worse, it is a missed opportunity to bring sustained soil health *with* boosted plant production. This group envisions a future in which inoculants of beneficial microbes exist, but in which they take a backseat to greater reform in the way agricultural soils are worked. As a researcher in Dijon told me, transforming agriculture for the betterment of soil health (and in turn human and planetary health) will require that companies that deal in mycorrhizal applications turn what has become a status quo business plan on its head. Inoculants, he explained, should be an emergency measure only, for the most severe of cases; the majority of a company's actions should involve working with farmers to analyze how they work their soils, and to find ways to change these practices in the interest of building native AM fungal communities. In this vision, inoculants become one tool among a larger toolkit that includes molecular soil and root tests; emergent databases of soil biology (across time, space, and ecological succession); cultivars bred for their ability to form robust symbiotic relationships. The researcher then re-stated his desired and predicted future for mycorrhizal applications in one sentence: instead of 10% consulting and 90% inoculants, mycorrhizal companies of the future will consist of 90% consulting.

PART III: Symbio-consulting, Another Future of Sustainable Agriculture

Thus far I have discussed a category of soilscapes (arable infrastructures) in which AM inoculants are most likely to reduce the need for irrigation and fertilization, ecosystem services that have little to do with biodiversity enhancement or the improvement of long-term soil health. I have argued that the term sustainability is often used ambiguously, suggesting that AM inoculants can bring a full array of ecosystem services that includes long-term benefits to soil health. However, the sustainability currently brought by AM inoculants is what Christopher Henke would call maintenance repairs to inherently resource intensive forms of plant production: AM inoculants used in arable infrastructures do not bring transformational soil repair, but the mitigation and fine-tuning of twentieth-century industrial agriculture. This is the line of argumentation brought by a group of researchers, most of whom work with experimental systems and settings and ask research questions that deal not with singular pairings of microbe and plant host, but with broader microbial-plant communities. They are part of a trend that analyzes and tinkers with mycorrhiza as more than a *singular symbiosis*, and their results now show how the symbiosis can drastically change depending on conditions as subtle as the density of host plants.[155] But how do researchers who are wary of the over-use of inoculants propose to bring symbiotic efficiencies to land-management? Commercial inoculants take on a liminal role, for emergency repairs and the most confined and regularly reworked of arable infrastructures (nurseries and sports stadiums). Those microbes—AM fungi included—that already dwell in the soil, even if dormant, take center stage (Sosa-Hernández Moisés 2019). This gives rise to a new approach to agriculture: sundry and emergent practices designed specifically to boost native microbial communities. This is a heterogenous and in many respects still-to-come class of knowledge practices that I refer to as symbio-consultants.

In calling for greater reform in the way that agrarian soils are managed, symbio-consultants do not shy away from the political-economy and deeper issues with the material infrastructures of industrial agriculture. As such, the greatest hurdle (and the greatest potential benefit) of symbio-consulting is the will to confront the political-economy of industrial agriculture, and the culturally and materially entrenched ways of working soil (industrial agricultural infrastructures). To be sure, techno-scientific hurdles remain; namely, the need for better molecular diagnostics, and plant breeding with mycorrhizae in mind. But those sympathetic to symbio-consulting recognize that social and political factors present greater

---

[155] The factors that impact how AM fungi act continue to emerge and multiple. For example, a nascent research topic concerns the species of AM fungi that live in the subsoil. Deeper soil layers have only recently been known as a habitat for AM fungi (Sosa-Hernández Moisés et al. 2019).

challenges, and for good reason: Symbio-consulting is in an unenviable position that threatens the profit margins of BioAg (what has become a multi-billion dollar inoculant industry) as well as the broader political economy of industrial agriculture.

Symbio-consultants, as a distinct group or sector, has (yet) to exist. It is an envisioned sustainable future for industrial agriculture, an alternative to a future in which soil drugs exist for a diverse array of crops, regions and soil types. These are two sustainable futures for industrial agriculture that features soil microbes.

As with the inoculant industry, aspects of symbio-consulting currently exist, albeit in a fragmented and nascent form. This includes the diagnostics of soil biology and guidance on how and when to plant crops (across space and time) so as to enhance those microbes already in the soil. Although a few individuals (often entrepreneurs with a freelance consulting service) devote their time and profession to working with soil symbionts, it is more common for consulting on how to improve a soil's microbial communities to come from those who work elsewhere in the agricultural sector.

Consulting for Transformation

Symbio-consultants differ greatly in their backgrounds and in the practices that they prescribe. On one end of the spectrum are those with a background in soil conservation, or forms of agriculture such as biodynamic or permaculture. Without abandoning such practices and land-use philosophies, their career turns exclusively to offering diagnostics or prescriptions on using soil biology to bring symbiotic efficiencies. A good example is microbiologist Elaine Ingham. I met with Ingham in her hometown of Corvallis, Oregon, where she worked in the Oregon State University Biology Department before running her own company that sold compost tea and offered soil-biology diagnostics. Although Ingham did not use the phrase "symbiotic efficiencies," the sentiment imbues the email blasts that promote Ingham's consulting services and which I have regularly received since we met. In the third person, this promotion reads as such: "Her mission is to show that the key to making any plant thrive, from the turf on golf courses to vegetables in the garden is to team up with suitable soil microbes."[156]

Ingham's expertise is on the complex phenomenon known as the soil food web (see Ames and Ingham 1984). When we meet in 2016 she had long since sold her company that provides diagnostics of soil biology; nor was she selling compost tea.[157] Currently, the commodity form that provides a livelihood for Ingham is seminars, classes and personal farm visits. She teaches accessible versions of the rather complex concept of the soil food web. She also publishes widely on the topic, which is about "building the biology in your soil" via successional stages of soil biology with specific ratios of fungi and bacteria for each stage. [158] As prescriptions that center on "building" biology and biological "succession" suggests, Ingham is out for greater soil health and restoration; this is not just a more efficient way to bring plant fertility within a reductive and industrial system of plant production.

Ingham's prescriptions center on planting schemes and a general rule of thumb that one should disturb the interior of the soil as little as possible.These practices stand in stark contrast to the arable infrastructure approach in which regular and severe soil disruption—or the repeated planting of the same crop—is followed by the regular replacement of soil microbes via

---

[156] I have received these emails roughly once a monthly from 2016 to 2019, this one is from August, 2018.

[157] Compost tea is an indeterminate assembly of microbes that one brews in water, just like tea, before adding it to soil. We can think of this as a highly complex form of in-vivo produced inoculants.

[158] Ingham's seminars and consulting packages are well known if not infamous among researchers and soil practitioners for their gross-simplification of the complexities of soil ecologics, and for the exorbitant prices that she charges. I cannot speak to the efficacy of Ingham's methods, but after speaking with a few farmers who have attended her classes, and gone on to introduce some of the ideas in their respective agrarian social circles, I can say that she has done important work spreading a consciousness for soil biology expertise. Fees and descriptions of her services are all prominent on her website: https://www.soilfoodweb.com/

inoculants (which, perhaps ironically, could include the compost tea which Ingham sold for decades).

Ingham, someone who provided diagnostics of soil biology back in the late twentieth century via a microscope, rather than with genetic readouts, has since gone on to consult farmers on how to change their practices for the betterment of soil biology. Ingham shows how symbio-consulting has been around for decades. She is also a good example of the political work required with practices that often run counter to the infrastructures of status-quo industrial agriculture. Ingham is a vocal opponent of industrial agriculture. Earlier in her career she left a job at the United States Environmental Protection Agency over disagreements on research that questioned the safety and use of genetically modified organisms (Ingham's work cast serious doubt on the safety of certain GMOs); she was a lead researcher for the famed Rodale Institute, which began in 1947 and is proudly self-promoted as "Pioneers of Organic Agriculture Research." As one Corvallis-based research told me "Elaine has a loud voice," and she "wears her politics on her sleeve." Both of these points are readily seen in even a cursory Google search, in which she is featured on many alternative agriculture blog entries, opinion pieces and YouTube video clips.

Ingham provides an example of the symbio-consulting that has been around for decades. But we can question the extent to which Ingham's approach is "transformational," in Henke's use of the term. This is because most who attend her seminars have already turned to non-industrial forms of agriculture (they may have experienced crop failures with industrial methods, or for another reason took on a commitment to farm in a way that causes less environmental harm). Critiques of Ingham's approach say that the rather drastic changes she asks farmers to make are not economically feasible for those with large acreage, or who are dependent on large farming machinery and cannot take on the added labor required to "build soil biology." For instance, Ingham may insist that farmers use soil amendments such as compost, or work new crops into their rotation, both of which may not be possible for a farmer who is limited by the use of machinery already bought, and which is necessary to in order to farm greater acerage.

Consulting for Industrial Agriculture

There is another less realized form of symbio-consulting for industrial farmers who cannot (or are not ready) to take the transformational steps involved in Inghams's seminars. This is symbio-consulting that is more congruous with status-quo industrial agricultural. This sort of symbio-consulting is well represented by a review paper co-authored by Philippe Lemanceau, the head of the agroecology lab at INRA Dijon. The authors call for "'going back to the roots' of "natural plant communities" as a way to move forward with more sustainable systems for plant production (Philippot et al. 2013; 797). Three years later, another team of researchers in plant-microbe interactions seconded the call by proposing "to go back to the roots of agriculture, relying more on internal regulatory processes compared with contemporary agriculture" (Bender et al. 2016; 449). Bender and colleagues argue that "approaches of the green revolution focused on external manipulations of ecosystems" (*ibid.*). This critique of the Green Revolution goes further than that of Andre Fortin, a key architect of the system of production for commercial AMF inoculants, who argued that the Green Revolution was not on the wrong track, but simply did not go far enough (see Chapter 3). Bender and colleagues forward the concept of "soil ecological engineering," which is a tech-heavy version of what I call symbio-consulting. They insist that this microbe-led form of agriculture is *not* simply a matter of "blindly enhancing soil biodiversity," or the "random inclusions of more species." (Philippot et al. 2016; 446).

This is to say that symbio-consulting is often about far more than encouraging farmers to minimize their tillage and enhance their crop rotation.[159] Mycorrhizal researchers consistently told me that plant breeding for symbiotic efficiencies is a sorely needed field of research. If it is to become important for future agriculture, symbio-consulting relies on more attention from plant breeders on how cultivars interact (or do not) with soil symbionts. This knowledge would give consultants a more refined ability to prescribe crop rotations and co-culturing schemes to optimize the AM symbiosis. This has already started to happen. As German mycorrhizal researcher Matthias Rillig wrote optimistically in an opinion piece (2016) that critiques the use of commercial inoculants: "Already, plant breeders are increasingly looking to the roots" (see also Bishopp and Lynch, 2015).

That symbio-consulting is not merely an extension of alternative agricultural movements such as organic and biodynamic is best seen in products that symbio-consultants prescribe. AM fungi can put up with a surprising array of chemical, and even anti-fungal products. When it comes to balancing the ecological harm and economic benefit of using certain insecticides or herbicides, symbio-consultants are not against many products that even the most lax of organic growers would not use. As one consultant told me with a chuckle, "I tell growers, if they must continue with glyphosate, go on…. Mycorrhizae have no problem with it." This consultant wanted to stress that there are many strategies for achieving efficiencies with soil symbionts; I interpret his comment as designed to challenge any neat green imagery of the industry that I may have held.

---

[159] Or to initiate planting schemes that are fine tuned to which crops host which communities of microbes; that is, planting systematically to build robust microbial communities. Some AM fungi will associate with many different crops; others are more limited in their plant hosts. Achieving a greater diversity of AM communities thus involves careful choices in what crops to plant in the same field at the same time (co-culturing), and how to plant successively (crop rotations).

Article titles that evoke returns to pre-industrial arable soils are more attention grabbing and ironic than descriptive. The researchers whom told me about a future in which symbio-consulting is prominent described a highly productive future of agriculture *and* one in which locally-specific microbial soil ecologies get to thrive (see also, Granjou and Phillips 2018). These researchers proudly state their ability to hold an ethic that simultaneously takes seriously the need to feed a global population of humans with the need to allow the greater flourishing of microbial soil lives. Still, even among tech-heavy symbio-consultants, I got the sense that they too hope for a future in which industrial agriculture looks drastically different—they would also welcome reform in which soil microbes are allowed to thrive beyond rounds of extreme tilling and chemical applications that come with seasonal harvests. To varying degrees, even those symbio-consultants who advise more incremental change (what Henke would call maintenance repairs to status-quo industrial agriculture) see greater reform in the way agrarian soils are treated as the inevitable future of industrial agriculture. Even if their prescriptions (or their prescriptions to farm advisors, who will then communicate directly with growers) seek smaller "pragmatic" changes, they see themselves as part of a broader project that is steering and quickening the process in which mid- and large scale farms more fully incorporate microbial life—a productivist harnessing of symbiotic efficiencies (progressivist language that many symbio-consultants and mycorrhizal researchers are not shy to use) for the benefit of planetary and human life alike.

CONCLUSION: Changing Infrastructures, a Feat of Symbio-politics

Dominic Boyer, in his contribution to *The Promise of Infrastructures* (2018), writes that "it takes willful action" to do away with existing infrastructures. Mycorrhizal researchers skeptical of commercial inoculants readily told me that a future agriculture that is less reliant on petrochemicals and is centered on more robust soil ecologies will require fundamental infrastructural reworking (e.g. equipment changes, changes in planting schemes). They are fully aware that this will involve changes to familial traditions of farming, now two or three generations old, that are fully entrenched (and have found economic success) in industrial and highly mechanized forms of agriculture (Barlett 1993). Such infrastructural changes will also jeopardize (or automatically preclude) numerous revenue streams of industrial agriculture. Beyond such practical political challenges, is the hurdle of even *thinking* beyond current infrastructures, whose roles and functions have become so thoroughly sedimented in the social and material fabric of industrialized nations (see Ballestero 2016).

In Chapter 3, I showed the historical contingencies that led to inoculants as being the primary route to "bring mycorrhiza back into agriculture." This was shaped by the knowledge infrastructures (a highly reductive form of biology and molecular biology [see Keller 2000]) and the material infrastructures (mechanized agriculture), which constituted and were linked to mid-twentieth-century industrial agriculture. Companies that supplied the tractors and sophisticated tillage equipment, bred the hybrid seed, and developed the chemical fertilizers that were so profitable, would only accept a way of incorporating beneficial microbes into agriculture that would supplement, not replace, these systems. The early architects of AM inoculants (who prided themselves on industrial "pragmatism," as described in Chapter 3) knew very well that those who profited from status quo industrial agriculture presented one of the greatest limiting factors to any new bio-technology (in addition to government regulations). Inoculants were a way to bring mycorrhiza into industrial agriculture while allowing the industrial system, as a whole, to continue.[160] However, commercial inoculants have been on the market for decades now, and they have received mixed results—some researchers are convinced of their efficacy in boosting plant production; few farmers are convinced of their ability to bring cost-savings. With greater calls for the reform of industrial agriculture (as opposed to an incremental "greening" from new fertilizers), the supposed *solution* of AM inoculants has become a *compromise.*

The debate over whether products or practices should lead the charge in bringing symbiotic efficiencies to future industrial agriculture comes down to questions of what AM fungi can be made to do, and who best can speak for the symbiosis. With soil biology now taken seriously vis-a-vis plant production, at stake are new definitions of soil health and soil repair: the ability to say when soils are managed appropriately, and how to amend them when they are not. This is "a matter of governance for entangled life forms," what Stefan Helmreich (2009) has called "symbio-politics." Whereas Helmreich uses the term to discuss who (or what political body) has rights to and ownership over seawater and its multitudinous genetic code (or should we say genetic capital), with mycorrhiza, symbio-politics concerns how best to achieve symbio-efficiencies—a determining factor in which industries will thrive and which companies will profit or go bankrupt. This question, in turn, comes back to divisions between forms of experimenting with and knowing mycorrhizal fungi, and whether the symbiosis is framed as a single host-symbiont pair or as constituted by broader communities of plants, fungi and bacteria.

The exhibits with mycorrhizae at the tramway and in the *Jardin des Sciences* show how mycorrhizal researchers interact with the general public, whose approval (or at least

---

[160] Support from those companies who profit from the industrial agricultural system is key—these companies control the distribution channels and sales teams which are how the vast majority of farmers (in France and the U.S.) hear about agricultural products and physically receive them.

comprehension) is needed for further public funding and to push forward a paradigm change in agricultural practice. But it also presents concerns of what sort of mycorrhizal science is being presented, and how. Do big-plant-little-plant displays reinforce an unrealistic view of the symbiotic efficiencies that come via commercial inoculants? As Sheila Jasanoff (2014) has shown, concepts such as public "outreach" and "understanding of science" do not capture the two-way flow of influence and knowledge that exists between researchers and lay publics. Diverse communities and practitioners (environmentalists, land-managers, petrochemical companies, gardeners, etc.) form networks that create economic value and socio-cultural, ethical values around mycorrhiza. My focus on public experiments was intended to bring more of this network to the foreground—to highlight the interface of lab-based research, public opinion and industry interest, with the goal of showing the broader infrastructures (of material spaces, documentation, discourse) that shape how the mycorrhizal symbiosis is researched and conceived in scientific communities, and the varied soilscapes in which the symbiosis inescapably dwells.

CONCLUSION

The twenty-first century has brought a wave of interest and attention to the mycorrhizal symbiosis. I have analyzed this wave of interest by looking at the production of two seemingly disparate objects: truffles and soil drugs. While these bio-objects attract different communities of practice, and different investors, they also share common ground. They are both forms of mycorrhiza manipulated in an effort to enhance and bring greater sustainability to the production of plants and mushrooms. In different ways, all of the chapters in this dissertation deal with the ideas of "sustainability" and "efficiency," from new ways of managing and valuing forested landscapes to new agricultural practices that seek to limit the use of fossil fuels and chemical products. Mycorrhizal practices shape and are shaped by concepts of sustainability in soil and forest management.

Ever since the 1930s, when Sir Albert Howard explained his conviction that it was mycorrhiza—not only nitrogen, phosphorus, and potassium (N-P-K)—that plants rely upon to remain healthy (Gieryn 1999), the symbiosis has been an ally of those who practice alternative methods of industrial agriculture, such as permaculture, organic, and biodynamic agriculture. The farmers, consultants, and product designers of such "alternative" methods of agriculture have remained on the margins of this dissertation. My attention has instead been on mycorrhizal communities of practice as they transition from esoteric mycological societies, loose networks of agrarian tinkerers, and the "early adopters" of future industries into an agriculture or practice that exists at the middle or industrial level.

I began with truffle foraging as an example of how an interest in, or a feeling for, mycorrhizal symbiosis can exist, and spread within, communities that include researchers and laypeople. The truffle foragers with whom I spoke developed an understanding of a natural, biological process (where and how truffles grow) not by leaving populated and developed landscapes (cf. Fine 1998) but by acquiring knowledge on organisms that can be found in backyards and city parks (as often as old-growth forests). The greatest argument for sustainability in truffle foraging in Oregon is that it is a way to build greater awareness of forest ecologies. And yet, simultaneously, the increasing interest in truffling in Oregon, and the nature of this new truffling culture, have led to the unsustainable harvesting of truffles, posing a risk to the reputation of Oregon truffles (by having unripe truffles on the market) and the health of Oregon's forests (in the form of damaged truffle lands).

Chapter 1 presents a unique case of scientific-lay interactions. With ample truffle science expertise in Corvallis, and plenty of new grounds for truffling, amateur truffle hunters were well-trained in how to collect and categorize truffles, and were well poised to make significant contributions to truffle science. These amateurs remained reliant on professionals to achieve scientific credit (only professionals can submit papers to certain journals; amateurs also do not have access to equipment for molecular analysis). This power dynamic notwithstanding, professional and amateur trufflers in Western Oregon treated each other with respect.

Such parity among those with different backgrounds and skill sets is also displayed in Chapter 2, in this case regarding agrarian and agronomic ways of knowing truffles, not in industrial or natural forests, but in truffle orchards. Truffle science and technology has made important advancements in the creation of truffle trees and the discovery of general growth parameters for *Tuber melanosporum*. However, as indicated by the thousands of mature melanosporum orchards with healthy trees yet no truffles, this science and technology is a necessary but not sufficient condition. Also required are context-specific farming skills. Tinkering with truffles in the laboratory is no replacement for tinkering with truffles in the orchard.

But the biology of truffles and the science of truffle farming are advancing rapidly (Martin et al. 2018; Le Tacon et al. 2016; Le Tacon 2017). Interest in truffle farming from industrialists and investors is also on the rise: one sign of this is the recent prevalence of truffle consultants from all corners of the world, advertising their services to small-scale Oregon truffle farmers. A few of these farmers told me about their concern with this sudden interest, not to mention that "large Californian landowners" will likely soon begin to farm truffles; this would ruin the bucolic and eco-friendly image of truffle farming, while lowering the price of truffles. Truffle farming is at a point in which there is enough standardization to embolden venture capitalists, yet the practice still requires individuals who are willing to experiment and gain knowledge that is tacit and specific to individual plots of land. Despite the existence of industrial truffle orchards (and of major truffle investors), for the time being, truffles remain symbols not of industrial farming but of a resistance to such agricultural practices.

That mycorrhiza is a symbol of resistance to scaling and industrialization while also being complicit in such techno-modernist projects remains a theme in the second half of the dissertation, which concerns mycorrhizal soil drugs. Chapter 3 centers on the creation of an *in vitro* system to produce AMF inoculants. Here I discuss a sustainability that makes unlikely bedfellows out of industrial agriculturalists (e.g. Norman Borlaug) and environmentalists (e.g. Rachel Carson). Those who argue that the inoculant form is *the* way to bring AM fungi to industrial agriculture do so out of "pragmatism." They may have deep qualms with industrial agriculture, but these inoculant producers have built careers, and ethical stances, on trying to mitigate the environmental ills of industrial agriculture. These inoculant producers are not out to transform the political economy of status quo agriculture; they rather seek to bring changes that they see as apolitical, as they will not disrupt any current agricultural sector. I show the work that goes into the production of contaminate-free inoculants that can be shipped across state lines. Equally important to the creation of the inoculants, I argue, is the creation of the spaces in which these inoculants will be effective. To this end, some inoculant producers describe industrial arable lands as "clean slates," in that they lack useful microbes (as opposed to the potent, beneficial new soil drugs) or their existing microbes are so weak, they don't risk making the soil drugs inefficacious.

This is not the case for all inoculant producers. Chapter 3 ends with those who produce inoculants using *in vivo* systems of production. These inoculant producers are not out to scale their systems of production, nor are they out to sell their products globally. Instead of talking about soils that are "clean" of functioning symbionts or of inoculants that are sterile, those who follow *in vivo* production methods argue for the value in the *indeterminacies* of soil ecologies, even the ever-shifting unknowns of the mycorrhizal symbiosis itself. In the 1980s, one such inoculant producer, Bob Linderman, coined the term mycorrhizosphere to capture this complexity.

Only in the last few years has the larger community of mycorrhizal researchers taken seriously the implications of the mycorrhizosphere. I discuss this shift in mycorrhizal science in Chapter 4. I show how a fracture has occurred in the mycorrhizal research community, in which some continue to work with experimental systems that feature mycorrhiza as *singular* (one plant, one fungus), while others insist on the need to experiment with *communities* of AM fungi, plants, and bacteria. Findings from vanguard mycorrhizal science point to unexpected "functional diversity" in AM fungi. This presents a hurdle for inoculant companies that want to claim that a few inoculant types are effective in soilscapes across the globe. As I show through a group of mycorrhizologists at a public research institute in Dijon, this new science puts mycorrhizal researchers in a bind: their work increasingly discredits the commercial inoculant industry, yet funding for their research relies on a strong inoculant industry, which is how they justify the economic and environmental "impact" of their work. So how do mycorrhizal researchers today justify their research? How do they see mycorrhiza bringing sustainability to the future of agriculture and soil management?

INRA researchers told me about two futures of mycorrhizal sustainability. One still has inoculants at its center. However, these inoculants are not used in agrarian soils so much as what I call arable infrastructures: confined and regularly overhauled soilscapes that include sports arenas and urban greenways. These are high-profile soilscapes, and their management is resource intensive. Moreover, these soilscapes often lack AM fungi and thus exemplify the microbial clean slates that inoculant producers told me are necessary to an inoculant's efficacy. Arable infrastructures also act as experimental settings in which researchers collect data; at times they even double as public demonstrations of mycorrhizal applications. As such, they connect with "green" initiatives that come from governmental and intergovernmental agencies.

The second, opposing view on the future of mycorrhizal sustainability came from another group of INRA researchers. For them, the above, singular view of mycorrhiza is misleading as to how the symbiosis operates the majority of the time, beyond highly manufactured arable infrastructures. These skeptical researchers say that inoculants cannot simply create sustainable agricultural practices all on their own, particularly in a world where agriculture needs to become a solution and not a problem to environmental issues in the twenty-first century. These researchers promote reformed agricultural practices. Through what I call symbio-consulting, they envision a new class of farm advisors who will reorient planting schemes, tillage regimes, and other agricultural practices, all in the name of enhancing soil microbes that already exist in a particular soil. Symbio-consulting is about maximizing "symbiotic efficiency" by nurturing microbes naturally found in soil, not by adding new ones. Although such consulting already exists, in the envisioned future of some researchers, symbio-consulting will become a major agricultural sector. These researchers told me that emergent technologies will be needed, such as more sophisticated molecular sequencing,[161] as well as breeding plants expressly for their ability to host soil symbionts. Thus, symbio-consulting is wrapped up in cutting-edge and as yet unrealized mycorrhizal science. It is also the mycorrhizal application that calls for the greatest reform to status quo agriculture, or what Christopher Henke calls transformational repair. Indeed, those researchers who told me about a future in which symbio-consulting is central were also not afraid to say that we must now confront the difficult political changes that are needed in agriculture. They were willing to admit that a future agriculture in which mycorrhiza plays a central role will require disrupting status quo revenue streams. This, they insisted, is the only way to make industrial agriculture sustainable, and to bring mycorrhiza back into agrarian spaces so that it can do what it does in nearly all other soilscapes.

---

[161] This is especially for AM fungi, whose diversity is currently hard to measure molecularly (see, Lekberg et al. 2018a).

BIBLIOGRAPHY

Ackerman-Leist, Philip. 2013. *Rebuilding the Foodshed: How to Create Local, Sustainable, and Secure Food Systems.* Santa Rosa, Calif.: Post Carbon Institute.

Altieri, Miguel A.. 1995. *Agroecology: the science of sustainable agriculture.* Boulder, Colo: Westview Press.

Altieri, Miguel A., and John G. Farrell. 2018. *Agroecology: the science of sustainable agriculture.* Boca Raton: CRC Press.

Anand, Nikhil, Akhil Gupta, and Hannah Appel, eds. 2018. *The Promise of Infrastructure.* Sar Advanced Seminar Titles. Durham: Duke University Press.

Andersen, Arden B.. 2000. *Science in agriculture: advanced methods for sustainable farming.* Austin, TX.: Acres U.S.A.

Anker, Peder. 2001. *Imperial Ecology : Environmental Order in the British Empire, 1895-1945.* Cambridge, Mass.: Harvard University Press.

Ballestero, Andrea. 2016. "On Infrastructure, Sponges, and Aquifers. Center for Energy and Environmental Research in the Human Sciences @ Rice, blog, January 19, 2016. http://culturesofenergy.com/andrea-ballestero-on-infrastructure-sponges-and-aquifers.

Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.* Durham N.C.: Duke University Press.

Baragatti, Meili, Paul-Marie Grollemund, Pierre Montpied, Jean-Luc Dupouey, Gravier Joël, Claude Murat, and François Le Tacon. 2019. "Influence of Annual Climatic Variations, Climate Changes, and Sociological Factors on the Production of the Périgord Black Truffle (Tuber Melanosporum Vittad.) from 1903-1904 to 1988-1989 in the Vaucluse (France)." *Mycorrhiza.* 29 (2): 113–25.

Barlett, Peggy F.. 1993. *American Dreams, Rural Realities : Family Farms in Crisis.* Studies in Rural Culture. Chapel Hill: University of North Carolina Press.

Basset, Yves, Alan J. A. Stewart, Vojtech Novotny, Scott E Miller, George D. Weiblen, and Olivier Missa. 2004. "Conservation and Biological Monitoring of Tropical Forests: The Role of Parataxonomists." *Journal of Applied Ecology* 41 (1): 163–74.

Basso, Keith H.. 1996. *Wisdom Sits in Places: Landscape and Language among the Western Apache.* Albuquerque: University of New Mexico Press.

Bear, Laura, Karen Ho, Anna Lowenhaupt Tsing, and Sylvia Yanagisako. 2015. "Gens: A Feminist Manifesto for the Study of Capitalism." Theorizing the Contemporary, Fieldsights, March 30. https://culanth.org/fieldsights/gens-a-feminist-manifesto-for-the-study-of-capitalism

Beck, Ulrich. 1992. *Risk society: towards a new modernity.* London: Sage Publications.

Beckham, Nikol. 2017. “Entrepreneurial Leisure and the Microbrew Revolution,” In *Untapped: Exploring the Cultural Dimensions of Craft Beer.* Chapman, Nathaniel G, J. Slade Lellock, and Cameron D Lippard (eds). First. Morgantown: West Virginia University Press.

Bender, S. Franz, Cameron Wagg, and Marcel G.A. van der Heijden. 2016. “An Underground Revolution : Biodiversity and Soil Ecological Engineering for Agricultural Sustainability.” *Trends in Ecology and Evolution* 31 (6).

Bergstrom, Dorothy. 1976. “Forestry Research: What’s New in the West. White paper for the Forest Service of the U.S. Department of Agriculture. Pacific Northwest Station. October 1976.

Berry, Wendell. 1996. *The Unsettling of America: Culture & Agriculture.* (3rd ed). San Francisco: Sierra Club Books.

Bever, J. D., P. A. Schultz, A. Pringle, and J. B. Morton. 2001. “Arbuscular mycorrhizal fungi: More diverse than meets the eye, and the ecological tale of why.” *BioScience* 51: 923–931

Birch, Kean and David Tyfield. 2013. “Theorizing the Bioeconomy: Biovalue, Biocapital, Bioeconomics or … What?” *Science, Technology, and Human Values* 38 (3): 299–327.

Bonito, Gregory, James M. Trappe, Pat Rawlinson, and Rytas Vilgalys. 2010. “Improved Resolution of Major Clades Within Tuber and Taxonomy of Species Within the Tuber Gibbosum Complex.” *Mycologia* 102 (5): 1042–57.

Borlaug, Norman E.. 1971. “Norman E. Borlaug : The Green Revolution, Peace and Humanity.” Cimmyt Reprint and Translation Series, No. 3. Mexico: International Maize and Wheat Improvement Center.

Bourdieu, Pierre. 1984. *Distinction: A Social Critique of the Judgement of Taste.* Cambridge, Mass.: Harvard University Press.

Bowen, Frances. 2014. *After greenwashing: symbolic corporate environmentalism and society.* Cambridge: Cambridge University Press.

Bowker, G.. 1995. Second nature once removed: Time, space and representations. *Time & Society.* 4, no. 1: 47–66.

Bowker, G.. 1994. *Science on the run: Information management and industrial geophysics at Schlumberger, 1920-1940.* Cambridge, MA: MIT Press.

Bowker, Geoffrey C., and Susan Leigh Star. 1999. *Sorting Things Out: Classification and Its Consequences*. Inside Technology. Cambridge, Mass.: MIT Press.

Bowker, Geoffrey C, Karen Baker, Florence Millerand, David Ribes. 2010. "Toward Information Infrastructure Studies: Ways of Knowing in a Networked Environment." In: *International Handbook of Internet Research*. Dordrecht : Springer Netherlands. 97–117.

Boyer, Dominic. 2018. "Infrastructure, Potential Energy, Revolution." In: Anand, Nikhil, Akhil Gupta, and Hannah Appel, eds. *The Promise of Infrastructure.* Sar Advanced Seminar Titles. Durham: Duke University Press.

Braun, Bruce. 2002. *The Intemperate Rainforest: Nature, Culture, and Power on Canada's West Coast*. Minneapolis: University of Minnesota Press.

Brillat-Savarin. 1834. *Physiologie Du Gout; Ou, Méditations De Gastronomie Transcendante : Dédié Aux Gastronomes Parisiens Par Un Professeur* (version Quatrième éd.). Quatrième éd. Paris: Tessier. http://catalog.hathitrust.org/api/volumes/oclc/8363629.html.

Brock, William Hodson. 2002. *Justus von Liebig: the chemical gatekeeper*. Cambridge: Cambridge University Press.

Bugos, Glenn E., and Daniel J. Kevles. 1992. "Plants as intellectual property: American practice, law and policy in world context". *Osiris*. 7: 75-104.

Burlison, W.L.. 1939. *Science and Agriculture (The Soybean).* New York: ERPI Classroom Films, Inc.

Büscher, Bram and Robert Fletcher. 2019. *The Conservation Revolution: Radical Ideas for Saving Nature beyond the Anthropocene*. New York: Verso Books.

Buttel, F.H.. 2000. "Ecological Modernization as Social Theory." *Geoforum*. 31: 57-65

Callison, Candis. 2014. *How Climate Change Comes to Matter: The Communal Life of Facts.* Durham: Duke University Press.

Callon, Michel. 1984. "Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay." *The Sociological Review* 32: 196–233.

Candea, Matei. 2010. "'I Fell in Love with Carlos the Meerkat': Engagement and Detachment in Human-Animal Relations." *American Ethnologist* Vol. 37, Nr. 2 (2010), S. 241-258.

Carson, Rachel. 1962. *Silent spring*. Boston: Houghton Mifflin.

Cassidy, Rebecca and Molly H. Mullin. 2007. *Where the Wild Things Are Now: Domestication Reconsidered.* Wenner-Gren International Symposium Series. Oxford: Berg.

Castree, Noel. 2003. "Commodifying what nature?" *Progress in Human Geography.* 27 (3): 273-297.

Ceballos I., M. Ruiz, C. Fernández, R. Peña, A. Rodríguez, and I.R. Sanders. 2013. "The in Vitro Mass-Produced Model Mycorrhizal Fungus, Rhizophagus Irregularis, Significantly Increases Yields of the Globally Important Food Security Crop Cassava." *Plos One* 8 (8): 70633.

Chen, Kunling, Yanpeng Wang, Rui Zhang, Huawei Zhang, and Caixia Gao. 2019. "CRISPR/Cas Genome Editing and Precision Plant Breeding in Agriculture". *Annual Review of Plant Biology.* 70 (1).

Churchman, G. J, and Edward Landa. 2014. *The Soil Underfoot: Infinite Possibilities for a Finite Resource*. Boca Raton, FL: CRC Press, Taylor & Francis Group.

Clark, Woodrow W, and Grant Cooke. 2016. *Smart Green Cities : Toward a Carbon Neutral World.* London: Routledge/Taylor & Francis Group.

Collen, Alanna. 2015. *10% human: how your body's microbes hold the key to health and happiness.* New York: Harper.

Collins, H. M. 2010. *Tacit and Explicit Knowledge*. Chicago: University of Chicago Press.

Conway, Gordon. 1997. *The doubly green revolution: food for all in the twenty-first century.* London, England: Penguin Books.

Cooper, Melinda. 2008. *Life as Surplus: Biotechnology and Capitalism in the Neoliberal Era.* Seattle: University of Washington Press.

Cornu, Pierre, Egizio Valceschini, and Odile Maeght-Bournay. 2018. *Une Histoire De L'inra, Entre Science Et Politique*. Versailles: Quae.

Corson C., K.I. MacDonald and B. Neimark 2013. "Grabbing 'green': Markets, environmental governance, and the materialization of natural capital." *Human Geography* 6(1):1-15

Cronon, William. 1992. *Nature's metropolis: Chicago and the Great West.* New York: W.W. Norton.

Davies, Kate. 2013. *The rise of the U.S. environmental health movement*. Lanham : Rowman & Littlefield Publishers

Dawkins, Richard. 2016. *The Selfish Gene*. 40th anniversary. Oxford Landmark Science. Oxford: Oxford University Press.

de la Bellacasa, Maria Puig. 2017. *Matters of Care: Speculative Ethics in More Than Human Worlds*. Minneapolis; London: University of Minnesota Press.

de la Bellacasa, Maria Puig. 2015. "Making Time for Soil: Technoscientific Futurity and the Pace of Care." *Social Studies of Science* 45 (5): 691–716.

de la Bellacasa, Maria Puig. 2014. "Encountering bioinfrastructure: Ecological struggles and the sciences of soil." *Social Epistemology* 28(1): 26–40.

De Master, Kathryn. 2018. "New Inquiries into the Agri-Cultures of the Middle." Culture, Agriculture, Food and Environment 40 (2): 130–35.

Declerck, Stéphane, D.G. Strullu, and André. J. Fortin. 2005. *In Vitro Culture of Mycorrhizas.* Soil Biology, 4. Berlin: Springer.

Delmas, J.. 1983. *La Truffe Et Sa Culture.* 2E éd. Paris: Institut national de la recherche agronomique.

Derelle, D., I. Dajoz, D. Carmignac, P. Genet, P.-E. Courty, S. Declerck, and I.M. Van Aarle. 2015. "Plant Identity and Density Can Influence Arbuscular Mycorrhizal Fungi Colonization, Plant Growth, and Reproduction Investment in Coculture." *Botany* 93 (7): 405–12.

Derrida, Jacques. 1984. *Of Grammatology.* Baltimore: Johns Hopkins University Press.
Dissoubray, Remy. 2018. "Tramway végétalisé : le micro-trèfle solution porte-bonheur de Dijon ? Une expérimentation débutée en 2014 et suivie de près." *Le Bien Public.* July 28, 2018. p.16.

Evernden, Neil. 1985. *The Natural Alien: Humankind and Environment.* Toronto: University of Toronto Press.

Faier, Lieba. 2018. "Introduction: Elusive Matsutake." *Social analysis* 62(4): 1-16.

Fairhead, James, Melissa Leach, and Ian Scoones. 2013. *Green grabbing: a new appropriation of nature.* London: Routledge.

Fine, Gary Alan. 1998. *Morel Tales: The Culture of Mushrooming.* Cambridge: Harvard University Press.

Fitzgerald, Deborah Kay. 2003. *Every farm a factory: the industrial ideal in American agriculture.* New Haven: Yale University Press.

Fleck, Ludwik. 1981. *Genesis and Development of a Scientific Fact.* Chicago: University of Chicago Press.

Fogle, Bruce. 2000. *The Encyclopedia of the Dog.* London: Dorling Kindersley.

Fortin, J. André, Christian Plenchette, and Yves Piché. 2016. *Les mycorhizes: l'essor de la nouvelle révolution verte.* Versailles: Editions Quae.

Fortin, Andre. 2015. "La recherche fondamentale, à quoi bon?" Le Soleil. Quebec City. Edition: 16 October 2015.

Fortun, Michael. 2008. *Promising genomics: Iceland and deCODE Genetics in a world of speculation*. Berkeley: University of California Press.

Fred, Edwin Broun, Ira Lawrence Baldwin, and Elizabeth McCoy. 1932. *Root nodule bacteria and leguminous plants*. Madison: University of Wisconsin.

Friedberg, Susanne. 2004. *French Beans and Food Scares: Culture and Commerce in an Anxious Age*. New York, N.Y.: Oxford University Press.

Fukuyama, Francis. 1989. The "End of History?". United States Institute of Peace in Brief, No. 11. Washington, D.C.: United States Institute of Peace.

Gianinazzi, Silvio, Armelle Gollotte, Marie-Noëlle Binet, Diederik van Tuinen, Dirk Redecker, and Daniel Wipf. 2010. "Agroecology: the key role of arbuscular mycorrhizas in ecosystem services". *Mycorrhiza*. 20 (8): 519-530.

Giddens, A., 1994. *Beyond Left and Right.* Stanford University Press, Stanford, CA.

Gieryn, Thomas F.. 1999. *Cultural boundaries of science: credibility on the line.* Chicago: University of Chicago Press.

Gieryn, Thomas F.. 1999b. "Hybridizing Credibilities: Albert and Gabrielle Howard Compost Organic Waste, Science, and the Rest of Society." in Cultural boundaries of science: credibility on the line. Chicago: University of Chicago Press.

Gieser, Thorsten. 2014. "Enskillment Inhibited: 'Industrial Gardening' in Britain." *Journal of the Royal Anthropological Institute* Vol. 20, No. 1(2014), S. 131-149.

Gilbert, Paul Robert. 2013. "Deskilling, Agrodiversity, and the Seed Trade: A View from Contemporary British Allotments." *Agriculture and Human Values : Journal of the Agriculture, Food, and Human Values Society* 30 (1): 101–14.

Gilkey, Helen M. 1949. "Sanford Myron Zeller: October 19, 1884-November 4, 1948." *Mycologia.* 41 (4): 357–68.

Gilman, Nils and Tobias Rees. "The Silent Microbiome Crisis." *The Washington Post*. Opinion: 2018 February 26, 2018

Giono, Jean. 1985. *The Man Who Planted Trees.* Chelsea, Vermont: Chelsea Green Pub.

Gliessman, Stephen R.. 2014. *Agroecology: the ecology of sustainable food systems*. Boca Raton: CRC Press.

Goodman, David, Bernardo Sorj, and John Wilkinson. 1987. *From farming to biotechnology: a theory of agro-industrial development*. Oxford: Basil Blackwell.

Graeber, David. 2013. "It Is Value That Brings Universes into Being." *Hau: Journal of Ethnographic Theory* 3(2). 219-243.

Granjou C, and Phillips C. 2018. "Living and Labouring Soils: Metagenomic Ecology and a New Agricultural Revolution?" *Biosocieties*.

Grasseni, Cristina. 2009. *Developing Skill, Developing Vision: Practices of Locality at the Foot of the Alps*. New York: Berghahn Books.

Grove, Richard. 1995. *Green Imperialism: Colonial Expansion, Tropical Island Edens, and the Origins of Environmentalism, 1600-1860.* Cambridge: Cambridge University Press.

Gudeman, Stephen. 2008. *Economy's Tension: The Dialectics of Community and Market*. New York; Oxford: Berghahn Books.

Gudeman, Stephen. 2001. *The Anthropology of Economy: Community, Market, and Culture.* Malden, Mass.: Blackwell.

Guerin-Laguette A., Hesson-Williams N, Wang Y. 2010. "Tuber brumale testing of truffières in New Zealand." In: *Proceedings of the 3rd International Congress on Truffles, Spoleto*, 25-28 November, 2008.

Guthrie, Frederick. 1896. "Inoculation of soil for leguminous crops." *The Agricultural Gazette of New South Wales* 7: 690–694.

Guy, Kolleen M. 2003. *When Champagne Became French: Wine and the Making of a National Identity*. Baltimore: Johns Hopkins University Press.

Hacskaylo, Edward. 1971. *Mycorrhizae: proceedings of the First North American Conference on Mycorrhizae*, April 1969. Washington, D.C.: U.S. G.P.O.

Hajer, M.A., 1995. *The Politics of Environmental Discourse: Ecological Modernisation and the Policy Process.* Clarendon Press, Oxford.

Hall, Ian R, Gordon T Brown, and Alessandra Zambonelli. 2007. *Taming the Truffle: The History, Lore, and Science of the Ultimate Mushroom*. Portland, Or.: Timber Press.

Haraway, Donna. 2016. *Staying with the trouble: making kin in the Chthulucene*. Durham: Duke University Press.

Haraway, Donna. 2008. *When Species Meet*. Minneapolis: University of Minnesota Press.

Haraway, Donna J. 2003. *The Companion Species Manifesto: Dogs, People, and Significant Otherness.* Chicago: Prickly Paradigm Press.

Haraway, Donna. 1997. *Modest_Witness@Second_Millennium.FemaleMan©_Meets_OncoMouse™: Feminism and Technoscience.* New York: Routledge.

Haraway, Donna Jeanne. 1976. *Crystals, Fabrics, and Fields: Metaphors of Organicism in Twentieth-Century Developmental Biology.* New Haven, Conn.: Yale University Press.

Harper, Douglas A. 2001. *Changing Works: Visions of a Lost Agriculture.* Chicago: University of Chicago Press.

Harkness H.W. 1899. *Californian Hypogaeous Fungi.* Proceedings of the California Academy of Sciences, series 3, 1:241–292.

Harré, Rom, Jens Brockmeier, and Peter Mühlhäuser. 1999. *Greenspeak: a study of environmental discourse.* Thousand Oaks, Calif: Sage Publications.

Harrison, Jill Lindsey. 2011. *Pesticide Drift and the Pursuit of Environmental Justice.* Food, Health, and the Environment. Cambridge, Mass.: MIT Press.

Hart, Miranda M., Pedro M. Antunes, and Lynette K. Abbott. 2017. "Unknown risks to soil biodiversity from commercial fungal inoculants". *Nature Ecology & Evolution.* 1 (4): 0115.

Harvey, David. 1990. *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change.* Oxford England: Blackwell.

Hawksworth D.L., and Lücking R. 2017. "Fungal Diversity Revisited: 2.2 to 3.8 Million Species." *Microbiology Spectrum* 5 (4).

Hays, Samuel P. 2007. *Wars in the Woods: The Rise of Ecological Forestry in America.* Pittsburgh, Pa.: University of Pittsburgh Press.

Healy, Rosanne A, Hannah Zurier, Gregory Bonito, Matthew E Smith, and Donald H Pfister. 2016. "Mycorrhizal Detection of Native and Non-Native Truffles in a Historic Arboretum and the Discovery of a New North American Species, Tuber Arnoldianum Sp. Nov." *Mycorrhiza* 26 (7): 781–92.

Helmreich, Stefan. 2016. "How to Hide an Island." *New Geographies* 08. Island: 82-87.

Helmreich, Stefan. 2009. *Alien Ocean : Anthropological Voyages in Microbial Seas.* Berkeley: University of California Press.

Helmreich, Stefan. 2008. "Species of Biocapital". *Science As Culture.* 17 (4): 463-478.

Hemenway, Toby. 2009. *Gaia's garden: a guide to home-scale permaculture.* White River Junction, Vt: Chelsea Green Pub.

Henke, Christopher. 2008. *Cultivating science, harvesting power: science and industrial agriculture in California*. Cambridge, Mass: MIT Press.

Herridge, D. F. 2011. *Managing legume and fertiliser N for Northern grains cropping*. Kingston Act: Grains Research & Development Corporation Publication.

Hetherington, Kregg, ed. 2019. *Infrastructure, Environment, and Life in the Anthropocene.* Experimental Futures. Durham: Duke University Press.

Hijri, Mohamed. 2016. "Analysis of a Large Dataset of Mycorrhiza Inoculation Field Trials on Potato Shows Highly Significant Increases in Yield." *Mycorrhiza* 26 (3): 209–14.

Hirsch, Eric. 1995. "Landscape: Between Place and Space." Pp. 1–30 in *The Anthropology of Landscape: Perspectives on Place and Space*, edited by Eric Hirsch and Michael O'Hanlon. Oxford: Clarendon Press.

Holthausen, Richard S, Robert G Anthony, Keith Baker Aubry, Kelly Burnett, Nancy Fredricks, Joseph Furnish, E. Charles Meslow, et al. 1994. Final Supplemental Environmental Impact Statement on Management of Habitat for Late-Successional and Old-Growth Forest Related Species Within the Range of the Northern Spotted Owl. Vol. Appendix J2, Results of Additional Species Analysis /. Portland, Or.?: U.S. Department of Agriculture, Forest Service.

Howard, Albert. 1943. *An agricultural testament.* London: Oxford University Press.

Howard, Albert, and Louise E. Howard. 1947. *The soil and health: a study of organic agriculture.* New York: Devin-Adair Co.

Huff, Amber and Andrea Brock. 2017. "Accumulation by Restoration: Degradation Neutrality and the Faustian Bargain of Conservation Finance." *Antipode*. Interventions section on Antipode website. Accessed on May 16, 2018. https://antipodefoundation.org/2017/11/06/accumulation-by-restoration/

Hull, Matthew S. 2012. *Government of Paper: The Materiality of Bureaucracy in Urban Pakistan*. Berkeley: University of California Press.

Ijdo M, S Cranenbrouck, and S Declerck. 2011. "Methods for large-scale production of AM fungi: past, present, and future". *Mycorrhiza*. 21 (1): 1-16.

Ingham, Elaine, Andrew R. Moldenke, and C. A. Edwards. 2000. *Soil biology primer.* Ankeny, Iowa: Soil and Water Conservation Society, in cooperation with the USDA Natural Resources Conservation Service.

Ingold, Tim. 1993. "The Temporality of the Landscape." *World Archaeology* 25 (2): 152–74.

Jackson, Wes. 2010. *Consulting the genius of the place: an ecological approach to a new agriculture.* Berkeley: Counterpoint Press.

Jacob, François. 1986. *Le Jeu Des Possibles: Essai Sur La Diversité Du Vivant.* Le Livre De Poche, Biblio Essais, 4045. Paris: Librairie générale française.

Janeja, Manpreet K, and Andreas Bandak, eds. 2018. *Ethnographies of Waiting: Doubt, Hope and Uncertainty*. London, UK: Bloomsbury Academic, an imprint of Bloomsbury Publishing, Plc.

Jasanoff, Sheila, and Sang-Hyun Kim. 2015. *Dreamscapes of modernity: sociotechnical imaginaries and the fabrication of power*. Chicago: University of Chicago Press.

Jasanoff, Sheila. 2005. *Designs on nature: science and democracy in Europe and the United States*. Princeton, N.J.: Princeton University Press.

Jasanoff, Sheila. 2014. "A Mirror for Science." *Public Understanding of Science* 23 (1): 21–26.

Jensen, Casper Bruun. 2015. "Experimenting with Political Materials: Environmental Infrastructures and Ontological Transformations." *Distinktion* 16 (1): 17–30.

Jones, Eric T. 2002. "The Political Ecology of Wild Mushroom Harvester Stewardship in the Pacific Northwest." Dissertation. University of Massachusetts at Amherst.

Jones, Eric T., Rebecca J. McLain, and James F. Weigand. 2002. *Nontimber Forest Products in the United States.* Lawrence, Kan.: University Press of Kansas.

Jones, Graham M. 2011. *Trade of the Tricks: Inside the Magician's Craft.* Berkeley: University of California Press.

Karlen, D.L., G.E. Varvel, D.G. Bullock, and R.H. Cruse. 1994. Crop rotations for the 21st century. Adv. Agron. 53:1–45.

Keller, Evelyn Fox. 2000. *The Century of the Gene*. Cambridge, Mass.: Harvard University Press.

Keller, Evelyn Fox. 1983. *A Feeling for the Organism: The Life and Work of Barbara Mcclintock.* San Francisco: W.H. Freeman.

Kellman, Kenneth. 2003 "The Role Of The Amateur In Bryology: Tales of an Amateur Bryologist." *Fremontia: A Journal of the California Native Plant Society*. Vol 31;3. 21-24.

Kirksey, Eben. 2014. *The Multispecies Salon*. Durham: Duke University Press.

Kirksey, S. Eben, and Stefan Helmreich. 2010. “The Emergence of Multispecies Ethnography.” *Cultural Anthropology* V. 25, No. 4 (2010), P. 545-576.

Klein, Naomi. 2007. *The Shock Doctrine: The Rise of Disaster Capitalism.* Toronto: Alfred A. Knopf Canada.

Kloor, Keith. 2015. “The Battle for the Soul of Conservation Science.” *Issues in Science and Technology* 31 (2): 74–79.

Kloppenburg, Jack Ralph. 1988. *First the seed: the political economy of plant biotechnology, 1492-2000.* Cambridge [Cambridgeshire]: Cambridge University Press.

Kohler, Robert E. 1991. *Systems of production: Drosophila, neurospora, and biochemical genetics*. Historical Studies in the Physical and Biological Sciences, V.22, Part 1.

Kohler, Robert E. 1994. *Lords of the Fly: Drosophila Genetics and the Experimental Life.* Chicago: University of Chicago Press.

Kohler, Robert E. 2002. *Landscapes & Labscapes: Exploring the Lab-Field Border in Biology.* Chicago: University of Chicago Press.

Koide, Roger T, and Barbara Mosse. 2004. “A History of Research on Arbuscular Mycorrhiza.” *Mycorrhiza* 14 (3): 145–63.

Kosek, Jake. 2006. *Understories: The Political Life of Forests in Northern New Mexico*. Durham: Duke University Press.

Kropotkin, Petr Alekseevich. 1915. *Mutual Aid: A Factor of Evolution.* Popular Edition. London: William Heinemann.

Kuhn, Thomas S. 1962. *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Landecker, Hannah. 2007. *Culturing Life: How Cells Became Technologies.* Cambridge, Mass.: Harvard University Press.

Larkin, Brian. 2013. “The Poetics and Politics of Infrastructure.” *Annual Review of Anthropology*. 42; 327-343.

Latour, Bruno. 2004. “Why Has Critique Run Out of Steam? From Matters of Fact to Matters of Concern.” *Critical Inquiry* 30 (2): 225–48.

Latour, Bruno. 1988. *The pasteurization of France*. Cambridge, Mass: Harvard University Press.

Latour, Bruno. 1999. *Pandora's Hope*. Cambridge, Mass.: Harvard University Press.

Latour, Bruno, and Catherine Porter. 1993. *We have never been modern.* Cambridge, Massachusetts: Harvard University Press

Lave, Jean, and Etienne Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation.* Cambridge England: Cambridge University Press.

Le Tacon François. 2017. *Les Truffes: Biologie, Écologie Et Domestication.* Nancy: AgroParisTech.

Le Tacon François, Andrea Rubini, Claude Murat, Claudia Riccioni, Christophe Robin, Beatrice Belfiori, Bernd Zeller, et al. 2016. "Certainties and Uncertainties About the Life Cycle of the Périgord Black Truffle (Tuber Melanosporum Vittad.)." *Annals of Forest Science: Official Journal of the Institut National De La Recherche Agronomique* (Inra) 73 (1): 105–17.

Lea T, Pholeros P. 2010. "This is not a pipe: the treacheries of indigenous housing." *Public Cult.* 22(1):187–209

Leach, Melissa, James Fairhead, and James Fraser. 2012. "Green grabs and biochar: revaluing African soils and farming in the new carbon economy". *Journal of Peasant Studies.* 39 (2): 285-307.

Lekberg Y, and T Helgason. 2018. "In situ mycorrhizal function - knowledge gaps and future directions". *The New Phytologist.* 220 (4): 957-962.

Lekberg Y, Vasar M, Bullington LS, Sepp SK, Antunes PM, Bunn R, Larkin BG, and Öpik M. 2018a. "More Bang for the Buck? Can Arbuscular Mycorrhizal Fungal Communities Be Characterized Adequately Alongside Other Fungi Using General Fungal Primers?" *The New Phytologist* 220 (4): 971–76.

Lien, Marianne E. 2015. *Becoming Salmon: Aquaculture and the Domestication of a Fish.* Oakland, California: University of California Press.

Light, Jennifer S. 2003. *From Warfare to Welfare: Defense Intellectuals and Urban Problems in Cold War America.* Baltimore: Johns Hopkins University Press.

Linderman R.G. 1988. Mycorrhizal interactions with the rhizosphere microflora: The mycorrhizosphere effect. *Phytopathology* 78:366-371.

Lock, Margaret. 2002. Twice Dead: Organ Transplants and the Reinvention of Death. Berkeley: University of California Press

Lorimer, Jamie. 2017. "Probiotic Environmentalities: Rewilding with Wolves and Worms". *Theory, Culture & Society.* 34 (4): 27-48.

Lorimer, Jamie. 2007. "Nonhuman Charisma." *Environment and Planning D: Society and Space* 25 (5): 911–32.

Lowe, Celia. 2006. *Wild Profusion: Biodiversity Conservation in an Indonesian Archipelago.* Princeton, N.J.: Princeton University Press.

Lowenfels, Jeff, and Wayne Lewis. 2010. *Teaming with microbes: the organic gardener's guide to the soil food web.* Portland: Timber Press.

Lowenfels, Jeff. 2017. *Teaming with fungi: the organic grower's guide to mycorrhizae.* Portland: Timber Press.

Lowenfels, Jeff. 2015. *Teaming with nutrients: the organic gardener's guide to optimizing plant nutrition.* Portland: Timber Press.

Lynch, Kathryn A, Rebecca J McLain. 2003. "Access, Labor, and Wild Floral Greens Management in Western Washington's Forests." General Technical Report Pnw, Gtr-585. Portland, OR: U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station.

Lyson, Thomas A. 2008. "Agriculture of the Middle: Lessons Learned from Civic Agriculture." Essay. *In Agriculture of the Middle: Lessons Learned from Civic Agriculture.* Eds: Lyson, Thomas A, G. W Stevenson, and Rick Welsh. Cambridge, Mass.: MIT Press. 165–78.

MacKenzie, Donald A, Fabian Muniesa, and Lucia Siu. 2007. *Do Economists Make Markets?: On the Performativity of Economics.* Princeton: Princeton University Press.

Margulis, Lynn. 2012. *Lynn Margulis: The Life and Legacy of a Scientific Rebel.* Edited by Dorion Sagan. White River Junction, Vermont: Chelsea Green Publishing.

Margulis, Lynn. 1994. "Symbiogenesis and Species Origin." *Origins of Life and Evolution of the Biosphere* 24 (2/4): 351–51.

Martin, Francis. 2015. "Convergent Losses of Decay Mechanisms and Rapid Turnover of Symbiosis Genes in Mycorrhizal Mutualists." *Nature Genetics* 47 (4): 410–15.

Martin, Francis. 2011. "Unearthing the Truffle Genome." *New Phytologist* 189 (3): 645–46.

Martin, Francis M, Maria J Harrison, Sarah Lennon, Lindahl Björn, Öpik Maarja, Andrea Polle, Natalia Requena, and Selosse Marc-André. 2018. "Cross-Scale Integration of Mycorrhizal Function." *New Phytologist* 220 (4): 941–46.

Maser, Chris, Andrew W Claridge, and James M Trappe. 2008. *Trees, Truffles, and Beasts : How Forests Function.* New Brunswick, N.J.: Rutgers University Press.

Matsutake Worlds Research Group. 2009. "A New Form of Collaboration in Cultural Anthropology." *American Ethnologist* Vol. 36, Nr. 2 (2009), S. 380-403.

Mazoyer, Marcel, and Laurence Roudart. 2006. *A history of world agriculture: from the neolithic age to the current crisis*. New York: Monthly Review Press.

McLain, Rebecca J, Eric T Jones. 2005. “Nontimber Forest Products Management on National Forests in the United States.” Pnw-Gtr, 655. Portland, OR: USDA, Forest Service, Pacific Northwest Research Station.

McLain, Rebecca J, Eric Jones. 1997. “Challenging 'Community' Definitions in Sustainable Natural Resource Management: The Case of Wild Mushroom Harvesting in the USA.” Gatekeeper Series, No. 68. London: IIED, International Institute for Environment and Development.

Melillo, Edward D. 2012. "The First Green Revolution: Debt Peonage and the Making of the Nitrogen Fertilizer Trade, 1840-1930". *The American Historical Review.* 117 (4): 1028-1060.

Mintz, Sidney W. 1986. *Sweetness and Power: The Place of Sugar in Modern History.* New York: Penguin Books.

Mitchell, Timothy. 2011. *Carbon democracy: political power in the age of oil.* New York: Verso.

Mol, Annemarie, Ingunn Moser, and J Pols, eds. 2010. *Care in Practice: On Tinkering in Clinics, Homes and Farms*. Bielefeld: Transcript. Verlag, Bielefeld

Mol, Annemarie. 2002. *The Body Multiple: Ontology in Medical Practice*. Durham: Duke University Press.

Mol, A.P. Arthur. 1996. “Ecological Modernization and Institutional Reflexivity: Environmental reform in the late modern age.” *Environmental Politics*. 5: 302-323.

Montgomery, David R., and Anne Biklé. 2016. *The hidden half of nature: the microbial roots of life and health*. New York: W.W. Norton & Company.

Moore A. 2018. "Selling Anthropocene space: situated adventures in sustainable tourism". *Journal of Sustainable Tourism.*

Moore, Jason W. 2015. “Cheap Food and Bad Climate: From Surplus Value to Negative Value in the Capitalist World-Ecology.” *Critical Historical Studies* 2 (1): 1–43.

Murat, Claude. 2015. “Forty Years of Inoculating Seedlings with Truffle Fungi: Past and Future Perspectives.” *Mycorrhiza* 25 (1): 77–81.

Nash, Linda Lorraine. 2006. *Inescapable ecologies: a history of environment, disease, and knowledge.* Berkeley: University of California Press.

Nicholson, Daniel J. and John Dupré. 2018. *Everything Flows: Towards a Processual Philosophy of Biology*. Oxford, United Kingdom: Oxford University Press.

Nixon, Rob. 2011. *Slow violence and the environmentalism of the poor*. Cambridge, Mass: Harvard University Press.

North American Truffling Society. 1987. *The Cookbook of North American Truffles*. Corvallis, OR (PO Box 296, Corvallis 97339).

Nouhra, Eduardo, and Michael A Castellano. 1995. "Nats Truffle and Truffle-Like Fungi 3: Gastroboletus Dinoffii Sp. Nov." *Mycotaxon* 55: 179.

Nowak, Zachary. 2015. *Truffle: A Global History*. Edible Series. London, UK: Reaktion Books.

OED. 2019. "arable, adj. and n." Oxford English Dictionary Online. Oxford University Press, June 2019. Web. 1 August 2019.

Ohlson, Kristin. 2014. *The soil will save us: how scientists, farmers, and foodies are healing the soil to save the planet*.New York: Rodale.

Olivier, Jean-Marc, Jean-Charles Savignac, and Pierre Sourzat. 2018. *Truffe Et Trufficulture*. Périgueux: Fanlac.

Oviatt, Peter. 2017. "Developing a BLM Truffling Permit." *The North American Truffler*. Publication of the North American Truffling Society (NATS).

Parnell, J. Jacob, Randy Berka, Hugh A. Young, Joseph M. Sturino, Yaowei Kang, D. M. Barnhart, and Matthew V. DiLeo. 2016. "From the Lab to the Farm: An Industrial Perspective of Plant Beneficial Microorganisms". *Frontiers in Plant Science*. 7.

Paxson H, and S Helmreich. 2014. "The perils and promises of microbial abundance: novel natures and model ecosystems, from artisanal cheese to alien seas". *Social Studies of Science*. 44 (2): 165-93.

Paxson, Heather. 2013. *The Life of Cheese: Crafting Food and Value in America*. Berkeley: University of California Press.

Peet, Richard, Paul Robbins, and Michael Watts. (eds.) 2011. *Global Political Ecology*. London: Routledge.

Philippot, L, J Raaijmakers, P Lemanceau, and van der, W.H Putten. 2013. "Going Back to the Roots: The Microbial Ecology of the Rhizosphere." *Nature Reviews Microbiology* 11 (11): 789–99.

Pickering, Andrew. 1995. *The Mangle of Practice: Time, Agency, and Science*. Chicago: University of Chicago Press.

Pilz, David and Randy Molina. 1996. "Managing Forest Ecosystems to Conserve Fungus Diversity and Sustain Wild Mushroom Harvests." General Technical Report Pnw, Gtr-371. Portland, Or. (333 S.W. First Ave., P.O. Box 3890, Portland 97208-3890): U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station.

Pilz, David, Charles Lefevre, Leslie Scott, James Julian. 2009. *Oregon Culinary Truffles: An Emergent Industry for Forestry, Agriculture & Culinary Tourism*. Available at: http://www.oregontruffles.org/truffles_feasibility_final.pdf. Accessed on July 10, 2019.

Polanyi, Michael. 2009. *The Tacit Dimension.* Chicago: University of Chicago Press.

Pollan, Michael. 2001. *The Botany of Desire: A Plant's Eye View of the World.* New York: Random House.

Powell, Jeff R, and Matthias C Rillig. 2018. "Biodiversity of Arbuscular Mycorrhizal Fungi and Ecosystem Function." *New Phytologist* 220 (4): 1059–75.

Pringle A., E. Barron, K. Sartor, J. Wares. 2011. Fungi and the Anthropocene: Biodiversity discovery in an epoch of loss. *Fungal Ecology* 4:121-123.

Rabinow, Paul. 1996. *Making PCR: A Story of Biotechnology.* Chicago: University of Chicago Press.

Raffles, Hugh. 2002. *In Amazonia: A Natural History.* Princeton, N.J.: Princeton University Press.

Raggio, Miguel, Nora Raggio, and John G. Torrey. 1957. "The Nodulation Of Isolated Leguminous Roots". *American Journal of Botany.* 44 (4): 325-334.

Raphael, Martin G, and R Molina. 2007. *Conservation of Rare or Little-Known Species: Biological, Social, and Economic Considerations.* Washington: Island Press.

Rawlinson, P, F Evans, and J. E Trappe. 1995. "The North American Truffling Society: Introduction to Its Series on Truffles and Truffle-Like Fungi." *Mycotaxon.* Ithaca New York. 55 (Com): 171–71.

Rebière Jean. 1967. *La Truffe Du Périgord: Sa Culture. Collection.* La Vie Rurale Moderne. Périgueux: Pierre Fanlac.

Rheinberger Hans-Jörg. 2012. "Experimental Systems: Difference, Graphematicity, Conjuncture." *Intellectual Birdhouse.* Artistic Practice As Research S. 89-99.

Rheinberger, Hans-Jörg. 1997. *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube.* Stanford: Stanford University Press.

Ricklefs, Robert E, Rick Relyea, and Christoph F Richter. 2015. *Ecology: The Economy of Nature.* Seventh edition, Canadian. New York, NY: W.H. Freeman and Company, a Macmillan Higher Education Company.

Rillig, Matthias C, Carlos A Aguilar-Trigueros, Tessa Camenzind, Timothy R Cavagnaro, Florine Degrune, Pierre Hohmann, Daniel R Lammel, et al. 2019. "Why Farmers Should Manage the Arbuscular Mycorrhizal Symbiosis." *New Phytologist* 222 (3): 1171–75.

Rillig, Matthias C, Anika Lehmann, Carlos A Aguilar-Trigueros, Janis Antonovics, Tancredi Caruso, Stefan Hempel, Johannes Lehmann, et al. 2016. "Soil Microbes and Community Coalescence." *Pedobiologia - Journal of Soil Ecology* 59 (1-2): 37–40.

Ritvo, Harriet. 1995. "Possessing Mother Nature: Genetic Capital in Eighteenth century Britain." In: *Early Modern Conceptions of Property*, ed. J. Brewer and S. Staves, 413–426. London: Routledge.

Robbins, Paul. 2012. *Political Ecology : A Critical Introduction* (version 2nd ed.). 2nd ed. Critical Introductions to Geography. Chichester, U.K.: J. Wiley & Sons.

Robbins, Paul. 2007. *Lawn People : How Grasses, Weeds, and Chemicals Make Us Who We Are*. Philadelphia: Temple University Press.

Robbins, William G. 1997. *Landscapes of Promise: The Oregon Story, 1800-1940.* Weyerhaeuser Environmental Books. Seattle: University of Washington Press.

Robertson M M. 2006. "The nature that capital can see: Science, state, and market in the commodification of ecosystem services." *Environment and Planning D: Society and Space*24(3):367-387

Rose, Nikolas S. 2007. *Politics of life itself: biomedicine, power, and subjectivity in the twenty-first century*. Princeton: Princeton University Press.

Rosendahl, Søren. 2008. "Communities, populations and individuals of arbuscular mycorrhizal fungi". *New Phytologist*. 178 (2): 253-266.

Rousseau. 1866. *Rapports Sur Les Truffières Artificielles De M. Rousseau Précédés*. D'une Introduction Par M. Loubet. Carpentras: E. Rolland.

Rubini, Andrea, Claudia Riccioni, Beatrice Belfiori, and Francesco Paolocci. 2014. "Impact of the Competition between Mating Types on the Cultivation of Tuber Melanosporum: Romeo and Juliet and the Matter of Space and Time." *Mycorrhiza* 24 (S1): 19–27.

Sacks, Oliver. 2002. *Oaxaca Journal.* National Geographic Directions. Washington, D.C.: National Geographic.

Sapp, Jan. 1994. *Evolution by Association: A History of Symbiosis*. New York: Oxford University Press.

Schaffer, Simon, and Steven Shapin. 2011. *Leviathan and the Air-Pump : Hobes, Boyle, and the Experimental Life.* Princeton: Princeton University Press.

Schenck, N. C., and George S. Smith. 1982. "Additional New and Unreported Species of Mycorrhizal Fungi (Endogonaceae) from Florida". *Mycologia.* 74 (1): 77.

Schumacher, E. F. 1989. *Small Is Beautiful: Economics As If People Mattered.* New York: Harper Perennial.

*Schwartz, Mark W, Jason D Hoeksema, Catherine A Gehring, Nancy C Johnson, John N Klironomos, Lynette K Abbott, and Anne Pringle. 2006. "The Promise and the Potential Consequences of the Global Transport of Mycorrhizal Fungal Inoculum." *Ecology Letters* 9 (5): 501–15.

Sellers, Christopher C. 1997. *Hazards of the job: from industrial disease to environmental health science.* Chapel Hill: University of North Carolina Press.

Shiva, Vandana. 1993. *Monocultures of the mind: perspectives on biodiversity and biotechnology.* London, UK: Zed Books.

Simard, Susanne. 1990. "A Retrospective Study of Competition between Paper Birch and Planted Douglas-Fir." Frda Report, 147. Victoria, B.C.: Forestry Canada, Pacific Forestry Centre.

Simon, J. C., Marchesi, J. R., Mougel, C., & Selosse, M. A. 2019. Host-microbiota interactions: from holobiont theory to analysis. *Microbiome.* 7(1), 5.

Singh, Harbhajan. 2006. *Mycoremediation: fungal bioremediation.* Hoboken, N.J.: Wiley-Interscience.

Smil, Vaclav. 2001. *Enriching the earth: Fritz Haber, Carl Bosch, and the transformation of world food production.* Cambridge, Mass: MIT Press.

Smith, S. E, and D. J Read. 2008. *Mycorrhizal Symbiosis* (version 3rd ed.). Amsterdam: Academic Press.

Smith, Neil. 1984. *Uneven Development: Nature, Capital, and the Production of Space.* New York, NY: Blackwell.

Sosa-Hernández Moisés A, Eva F Leifheit, Rosolino Ingraffia, and Matthias C Rillig. 2019. "Subsoil Arbuscular Mycorrhizal Fungi for Sustainability and Climate-Smart Agriculture: A Solution Right Under Our Feet?" *Frontiers in Microbiology* 10.

Soto Laveaga, Gabriela. 2009. *Jungle Laboratories: Mexican Peasants, National Projects, and the Making of the Pill.* Durham NC: Duke University Press.

Sourzat, Pierre. 2017. "Truffle Cultivation in the South of France: Technical Progress and Prospects." *Scientia Fungorum* 46: 63-72.

Sourzat, Pierre. 2008. *Le Principe De Précaution En Trufficulture.* Le Montat: Station d'expérimentation sur la truffe.

Sourzat, Pierre. 2004. *Questions D'écologie Appliquées À La Trufficulture.* Le Montat (France): Station d'Expérimentation sur la Truffe.

Spatafora, Joseph W, Ying Chang, Gerald L Benny, Katy Lazarus, Matthew E Smith, Mary L Berbee, Gregory Bonito, et al. 2016. "A Phylum-Level Phylogenetic Classification of Zygomycete Fungi Based on Genome-Scale Data." *Mycologia* 108 (5): 1028–46.

Star, Susan Leigh. 1999. "The Ethnography of Infrastructure." *American Behavioral Scientist* 43 (3): 377–91.

St-Arnaud M, Hamel C, Vimard B, Caron M, Fortin JA. 1996. "Enhanced hyphal growth and spore production of the arbuscular mycorrhizal fungus Glomus intraradices in an in vitro system in the absence of host roots." *Mycological Research.* 100:328–332.

St. John, Ted. 2002. *A Practical Guide to Mycorrhiza.* Online guide accessed on August 5, 2019. http://www.mycorrhiza.org/.

Stengers, Isabelle. 2018. *Another Science Is Possible: A Manifesto for Slow Science.* Translated by Stephen Muecke. English. Cambridge, UK: Polity Press.

Stone, Glenn Davis. 2010. "The anthropology of genetically modified crops". *Annual Review of Anthropology.* 39: 381-400.

Sunder Rajan, Kaushik. 2012. *Lively Capital: Biotechnologies, Ethics, and Governance in Global Markets*. Durham: Duke University Press.

Sunder Rajan, Kaushik. 2006. *Biocapital: the constitution of postgenomic life*. Durham: Duke University Press.

Taber, Peter. 2017. "Infrastructures of Environmental Governance." *Anthropology Today* 33 (6): 16–20.

Taussig, Karen-Sue, Klaus Hoeyer, and Stefan Helmreich. 2013. "The Anthropology of Potentiality in Biomedicine". *Current Anthropology.* 54 (S7): S3-S14.

Terrio, Susan J. 2000. *Crafting the Culture and History of French Chocolate*. Berkeley: University of California Press.

Thomas, Paul, and Ulf Büntgen. 2019. “A Risk Assessment of Europe's Black Truffle Sector Under Predicted Climate Change.” *Science of the Total Environment* 655: 27–34.

Trappe, J. M, and M. A Castellano. 2000. “New Sequestrate Ascomycota and Basidiomycota Covered by the Northwest Forest Plan.” *Mycotaxon.* Ithaca: New York 75: 153–80.

Trappe, Matthew J, James M Trappe, and Gregory M Bonito. 2010. “Kalapuya Brunnea Gen. & Sp. Nov. and Its Relationship to the Other Sequestrate Genera in Morchellaceae.” *Mycologia* 102 (5): 1058–65.

Trappe, JM, and Pacific Northwest Research Station (Portland, Or.). 2009. *Diversity, Ecology, and Conservation of Truffle Fungi in Forests of the Pacific Northwest.* General Technical Report Pnw, Gtr-772. Portland, OR: U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station.

Trappe, JM. 1977. “Selection of Fungi for Ectomycorrhizal Inoculation in Nurseries.” *Annual Review of Phytopathology* 15 (1): 203–22.

Trappe JM. 1975. “Helen Margaret Gilkey. 1886-1972.” *Mycologia.* 67 (2): 207–13.

Trappe, JM. 2005. “A.B. Frank and Mycorrhizae: The Challenge to Evolutionary and Ecologic Theory.” *Mycorrhiza* 15 (4): 277–81.

Tsing, Anna Lowenhaupt, Heather Anne Swanson, Elaine Gan, and Nils Bubandt. 2017. *Arts of living on a damaged planet.* Minneapolis: University of Minnesota Press.

Tsing, Anna Lowenhaupt. 2015. *The mushroom at the end of the world: on the possibility of life in capitalist ruins.* Princeton: Princeton University Press.

Tsing, Anna. 2000. “The Global Situation.” *Cultural Anthropology* 15 (3): 327–60.

Tutton, Richard. 2011. “Promising pessimism: reading the futures to be avoided in biotech.” *Social Studies of Science.* 41(3):411–429.

Van der Ploeg, R.R., W. Böhm, and M.B. Kirkham. 1999. "On the origin of the theory of mineral nutrition of plants and the Law of the Minimum." *Soil Science Society of America Journal.* 63-1055-1062.

Van Dooren, Thom. 2014. *Flight ways: life and loss at the edge of extinction.* New York: Columbia University Press.

Van Vleet, Eric. 2018. *Truffles Have Never Been Modern: An Actor-Network Theorization of 150 Years of French Trufficulture.* Doctoral Dissertation from the Florida International University.

Vaughan, Diane. 1996. *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA*. Chicago: University of Chicago Press.

Veblen, Thorstein. 1899. *The Theory of the Leisure Class.* New York. MacMillan.

Vermeulen, Niki, Sakari Tamminen, and Andrew Webster. 2012. *Bio-Objects: Life in the 21st Century.* Theory, Technology and Society. Burlington, VT: Ashgate.

von Uexkull, J. 1957. "A stroll through the worlds of animals and men", in *Instinctive Behavior* Ed. C Schiller. International Universities Press, New York. pp. 5- 80.

Walley, Christine J. 2013. *Exit Zero: Family and Class in Postindustrial Chicago.* Chicago: University of Chicago Press.

Werner, Peter G. 2006. "Pioneers of California Mycology: H. W. Harkness. *Mycena News: Newsletter of the Mycological Society of San Francisco*. December 2006.

White, Richard. 1996. "Are You an Environmentalist or Do You Work for a Living?" *Uncommon Ground: Rethinking the Human Place in Nature.* Ed. William Cronon. New York: W.W. Norton.

White, Richard. 1996. *The Organic Machine.* Critical Issue. New York: Hill and Wang.

Whiteside, Matthew D, Gijsbert D.A Werner, Victor E.A Caldas, Anouk van't Padje, Simon E Dupin, Bram Elbers, Milenka Bakker, et al. 2019. "Mycorrhizal Fungi Respond to Resource Inequality by Moving Phosphorus from Rich to Poor Patches Across Networks." *Current Biology* 29 (12): 2043–50.

Williams, Raymond. 1985. *Keywords: A Vocabulary of Culture and Society.* Rev. New York: Oxford University Press.

Wohlleben, Peter, Tim F Flannery, and S Simard. 2016. *The Hidden Life of Trees: What They Feel, How They Communicate : Discoveries from a Secret World.* Translated by Jane Billinghurst. Vancouver, BC, Canada: David Suzuki Institute.

Wolfe, Cary. 2010. *What is posthumanism?* Minneapolis: University of Minnesota Press.

Woody R.C, and Schmidt R. 2013. "Following the Roots of Oregon Wine." *Oregon Historical Quarterly* 114 (3): 324–39.

Worster, Donald. 1994. *Nature's economy: a history of ecological ideas*. Cambridge: Cambridge University Press.

Worster, Donald. 2004. *Dust Bowl: the southern Plains in the 1930s*. New York: Oxford University Press.

Wurgaft, Benjamin Aldes. 2019. *Meat Planet: Artificial Flesh and the Future of Food.* Oakland, California: University of California Press.

Yates-Doerr, Emily. 2017. “Where Is the Local?: Partial Biologies, Ethnographic Sitings.” *Hau: Journal of Ethnographic Theory* 7 (2): 377–401.

Yong, Ed. 2016. *I contain multitudes: the microbes within us and a grander view of life.* New York: Ecco.

Zak, Donald R., Peter T. Pellitier, William A. Argiroff, Buck Castillo, Timothy Y. James, Lucas E. Nave, Colin Averill, et al. 2019. "Exploring the role of ectomycorrhizal fungi in soil carbon dynamics". *New Phytologist.* 01: 13.