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THEMATIC COLLECTION: SITUATING MICROBES ORIGINAL RESEARCH ARTICLE

Knowing Enough and Space-Making for Microbes in Sake Fermentation Practices

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Abstract

This paper examines how one comes to know microbes in fermentation settings. Based on praxiographic data from field research at a sake brewery in Japan, the paper analyzes how brewers work in an anticipatory manner to make spaces that encourage certain microbes to thrive throughout the recurring steps of fermentation—an approach one might call space-making. While the hegemony of western science prioritizes technoscientific ways of knowing precisely which microbes are active and why, western science is not the only epistemic framework for encountering microbial life, and so this paper takes seriously the provocation of what it means to practice a form of *knowing enough* through which one can know microbes otherwise. After elaborating on different fermenting spaces, its tools, and its cleaning practices, the paper discusses the tension that arises between the temporalities of microbial metabolisms and temporalities of laboratory/scientific equipment. The paper concludes with thoughts on a form of knowing microbes that is based on inquiry and interdependence, evading modernist schemas of control.

Keywords

fermentation; microbes; ways of knowing; knowing enough; space-making; temporality

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Introduction

Fermentation is unruly. Sometimes referred to as an art and at others a science, fermentation relies on the unpredictable lives of various microbes, which characterize the process with more uncertainty compared to other modes of food processing (e.g. canning, dehydrating).[1] As a result, the incremental practices of fermentation—at some level—asks the fermenter to determine what is happening (microbially), as well as *how* or even *if* one should intervene. Assessing microbial work can depend on a range of tools (e.g., microscopes, pH strips, one's nose or tongue), for each of these can differentially measure microbial parts (e.g. genes) or microbial effects (e.g. acids). It is precisely this variability that fermentation invites multiple ways of knowing microbes.

Fermentation is a way of working within microbial worlds. It is an extant, hands-on method of directly engaging *with* microbes, *with* histories of working—*with* them long before microbes became known as such. In the current context of probiotics and gut hacks, the hype surrounding fermentation may appear to offer a mutually beneficial living arrangement with these microscopic beings: we help each other live on, so to speak. But the material practices of fermentation entail just as much annihilation and violence as it entails engendering environments for (certain) microbial thriving. In this sense, fermentation sheds light on when to kill, how, and to what degree, and operationalizes relational questions of how to continue living together in compromised times (Hey, forthcoming). More than a mere food phenomenon, fermentation practices go beyond managing objects and become a way of knowing microbes otherwise.

This paper examines knowing microbes in practices of fermentation, with attention to the spaces, tools, and tasks that fermenters at a brewery sustain daily, seasonally, and generationally. It is based on praxiographic data from an ethnography conducted at a Japanese sake brewery that relies exclusively on endogenous microbes. By analyzing what I call space-making practices, I show: (a) how these practices allow brewers to grapple with microbial uncertainty, and (b) how their practice of *knowing enough* represents a tension between specific knowing and time, which, in brief, posits that more precise methods to determine microbial identity take time away from space-making practices and threaten the operation of the entire brewery.

This paper relies on the concept of microbial apparatuses—in the Baradian sense of the term—which are used to ascertain and produce microbial knowledges. My use of Karen Barad's term stems from acknowledging the complicity (what she calls "entanglements") between the devices, measurements, and

[1] Fermentation, as a category, spans myriad sectors and with it come differential definitions about what it is and where it takes place (e.g., biological definitions that abide by its functional ability to anaerobically respire, versus a posthumanities definition of material-semiotic transformation enabled by micro-organisms). The scope of this paper focuses on fermentation of the food and beverage variety, meant for human consumption and thriving, at the scale of small enterprises. So, here, the term "fermentation" should be read with an imaginary asterisk at every instantiation, specifying "small-scale food fermentation" and not large-scale industry, or even soil fermentation (i.e., composting), waste fermentation (i.e., bioremediation), intestinal fermentation (i.e., digestion) and the like—although there may be some generative tensions that would help fermentation scholars nuance what holds or doesn't in each of these microbially-inflected transformations.

persons that configure, and continually reconfigure, spaces of knowledge production. She writes, for instance, that "entangled practices of knowing and being are material practices" (2007, 379). As such, I use the term apparatuses to mean not only the technological devices that measure what is happening (e.g., temperature probes); they can also include embodied tools (e.g., hands, tongue) and tacit "devices" (a metaphor that Karin Knorr Cetina uses to describe scientists' bodies). Thus, the phrase "microbial apparatuses" refers to this expanded query of "how one comes to know microbes" including the configuration of tools, both technological and tacit, used in microbial knowledge production.

I focus on these modes of knowing because the tools and devices affect what is measured and how, which are thought to reflect the quality of knowledge produced, where precision is presumed to be the ideal of knowing in the context of capitalist dreams for optimization and perpetual growth (Raffaetà 2023; Helmreich 2007). Yet, western science is not the only epistemic framework for making sense of microbes. For one, humans have been fermenting for millennia longer than scientific apparatuses could identify and name microbes as its catalyst or its threat. As such, this paper takes seriously the provocation of what it means to ferment at the scale of a business venture (a brewery) while practicing a form of knowing enough. In so doing, it raises the question about an acceptable level of imprecision correlated with the methods used to construct, and operationalize, microbial knowledge(s).

The paper is structured as follows. I first offer some background on how one comes to know microbes in fermentation settings, along with some technical details for how microbes are agential in fermentation. Next, I situate my argument within existing discourses of how (microbial) knowledge construction has heretofore shaped what microbes are in the process of brewing sake. This is followed by explanations that contextualize my methodological approach, which was characterized by praxiographic, multispecies, and multisensory sensitivities. I then describe three instances of brewing—making a fungal ingredient in sake-brewing, choosing tools when starting sake-starters, and cleaning rituals—to explain how brewers epitomize space-making practices. I connect these practices to knowing enough, which involves a discussion on temporalities. I analyze knowing enough in the context of knowing how and knowing why, with conclusions that show fermentation as a mode of knowing microbes through practice.

How One Comes to Know Microbes

Knowing Microbes in Science (and its Limits)

Knowing microbes in a fermentation setting frequently evokes Louis Pasteur and his namesake procedure for sterilizing liquids like meat broths and wine. Or, it evokes Elie Metchnikoff and his yogurt experiments to ward off cholera. These historical examples have become narrativized to the point where they have shaped how microbes are imagined to be in western paradigms: as agents of disease and decay or agents of health and prophylaxis, respectively. This framing casts microbes as entities to oversee and steward, which continues into the contemporary moment with the likes of precision fermentation.[2]

[2] My thanks to Alicia Ng for pointing out the continuity of this framing.

Scrutinizing the knowledge-making practices of microbiology in nineteenth-century France, Bruno Latour analyzes the forces that shaped Pasteurian knowledge, arguing that "translating" what microbes are from the laboratory to the rest of society, were instrumental "to discover the 'true' agent" that is the microbe (1993, 81). Discovering microbes, in this sense, was less a reveal of some underlying fact, but instead "discovery" meant carving out a nameable entity called "microbes" as distinct entities caught up in particular configurations. These configurations included people (Pasteur himself, his followers, and public health officials), places (laboratories, in sheep bodies), infrastructures (publishing outlets) and sociopolitical movements (hygienism) of the time (ibid., 89). By disproving the then prevailing idea that disease and rot simply happened (i.e. spontaneous germination), Pasteur (along with Robert Koch and others in early bacteriology) cast microbes as causative agents (i.e., germs) in modern germ theory. Most sterilization techniques and cleaning protocols of contemporary breweries still follow this Pasteurian line of reasoning, along with public health institutions who often oversee hygiene certification that preside over fermentation businesses today.

Shifts in technology have shifted what microbes are. Anton von Leeuwenhoek's forays in early microscopy determined microbes as "animalcules" or "little animals" based on what he saw to be animal-like movements but at a smaller scale of life (Lane 2015). While microscopes may be the primary apparatus for making microbes visible and thus known morphologically, recent genetic methods (e.g., metagenomics, sequencing) show microbes being abstracted into code:

> Despite what scientists say about finally being able to see microbes in vivo, what they really see is not microbes but fragments of their genome. [Here, the apparatuses] . . . (microscopes, omics technologies) manipulate one's objects of study (microbes) such that they become known differentially (as little animals, as fragmented code) (Raffaetà 2023, 71).

How one comes to study microbes shape those objects of study. Astrid Schrader demonstrates this in her study on how microbes became differentially known across different epistemic contexts:

> . . . how we get to know a species experimentally cannot be separated from the ontological question of what/who they are, [cautioning us how] the question is ill-posed if it asks, "who toxic [microbes] are" [before] "what they do" is established (2010, 277, original emphasis).

Schrader uses Baradian intra-actions and "meaning-making apparatuses" (ibid., 283) for argumentation, building on Barad's notion of ethico-onto-epistem-ologies (2007, 90). With apparatuses, knowing microbes does not mean having a human-with-tool on one side interacting with microbes-of-study on the other; rather, apparatuses entail the intra-acting agencies across humans, microbes, tools, environments, and more. Or, as Barad notes, the "relationship between the apparatuses of bodily production and the phenomena produced is one of 'agential intra-action'" (2003, 814). By using the related concepts of apparatuses, intra-action, and agencies, this paper interrogates the knowledge-making processes of microbes outside of laboratory (or strictly biological) settings because how one comes to know microbes epistemologically shapes what it is that microbes are or become ontologically. Studying how microbes become known, by whom, and by which apparatuses points to the plurality of multiple microbial knowledges.

In brewing contexts, apparatuses for knowing microbes can range from genetic tools (e.g., next-generation sequencing, PCR amplification) to culturing methods (e.g., growing on various agar media) to sensory methods (e.g., taste, smell, touch). Genetic sequencing only shows traces of what once lived and does not always discriminate between currently living and already dead microbes. Culturing methods, by definition, show what is alive, but only a small fraction of microbes can be cultivated under laboratory settings and take time for colonies to form.[3] Collectively, these scientific measurements provide a mere snapshot of past microbial moments that are no longer applicable by the time the data is produced. This is because, while data is being processed, time does not neutrally stand by and microbes are continuing to process whatever substrates are around them, morphing and shifting in population size and biodiversity.

This reality suggests a tension that arises between the temporalities of microbial metabolism (upon which fermentation and other microbial processes like compost or infections depend) and the temporalities of scientific tools and apparatuses in laboratory settings which construct knowledges about microbes. My argument for "knowing enough" holds the tension between the time of measuring microbial activity and time that microbes spend metabolizing substrates in the meantime. As I will argue in later sections, working with microbes in brewing and fermentation settings take multiple temporalities into account, calculating priorities between assessing microbes and intervening.

Knowing Microbes through Fermentation

Fermentation knew of microbes long before microbes were named as such (see, for example, Herrera 2018; Lee 2021). Microbes are lively, which means that fermenters are tasked with attending to microbial needs—in terms of climate, feed, and biodiverse communities to name a few—to keep their metabolic and reproductive cycles turning. After all, fermentation depends on such cycles. Characteristic of fermentation processes is the constant, and rapid, change of microbial populations, such that microbes fluctuate in both number (i.e., population density) as well as species (i.e., biodiversity). Thus, the hands-on practices of fermentation could be construed as human labor, but it would be more accurate to state that fermentation is *microbial* labor and human's making spaces for microbes to work with/in such spaces.

Adjustments can happen directly (adding vials of lab-optimized microbes), but the indirect practices are what I call "space-making." Indirectly "adjusting" microbes means making changes to a microbial environment, through the likes of adding substrates or shifting temperature, salinity, acidity, or oxygen availability—to which ambient microbes respond. This can either privilege or prevent certain microbes in their thriving. Thus, fermentation does not easily follow the formula of microbe plus substrate to produce a ferment since it requires particular configurations of multiple species (including at least humans and many different microbes) in a space. Matthäus Rest calls attention to these elements as "the preconditions of fermentation" including the technical and spatial requirements, like electricity in

[3] See microbial dark matter (MDM) for more information on scientists' quests to understand microbes that cannot be cultured in laboratory settings.

incubators, "that provided [the] cultures with the right environment to grow" (2017).[4] This is where the extent of knowing can matter, because knowing the relationship between these preconditions and which microbes are active can determine how fermented products can be named, packaged, distributed, monetized, and regulated (see Paxson 2013, for a thorough discussion on regulatory practices of raw-milk cheeses, whose highly microbial content invokes what she calls microbiopolitics). Rather than focus on the fermented products and what they mean or how they circulate in a social, political, or economic contexts, my focus is on the making of ferments, making sense of microbes, and making microbial knowledges.

Despite its rich social history, fermentation has recently been mobilized in the social sciences *as a research method* precisely because it takes microbial liveliness into account. At a home scale especially, fermentation goes beyond technoscientific apparatuses for knowing microbes to engage with embodied means, including "tuning in" to microbial timescapes through sensory information (Sariola 2021a) as well as "attunement" towards human and microbial call-and-response (Hey 2021) and recurring care practices (McConnell 2023). Across food-making contexts, working with lively microbes entails a mix of adjusting spaces, tools, and practices—interdependently—to situate the microbe in its metabolic trajectory. By doing the work of fermentation, one works with microbial apparatuses under analytical study.

Methodology

Methodologically, fermentation asks the researcher to engage in adaptive, embodied, and emplaced ways with the goal of analyzing how exactly humans, microbes, and ferments co-constitute one another. To accomplish this, I conducted field research with a Terada Honke (TH).[5] This sake brewery does not use lab-optimized or purified strains of bacteria, yeast, or molds. Instead, most of the fermentation steps entail gathering the endogenous environmental microbes that already live inside the brewing space. To study the microbes at any given step of fermenting sake thus required attending to what I am calling "space-making practices" inside the brewery.

I worked alongside my interlocutors as an apprentice brewer over two consecutive brewing seasons, which allowed me to immerse myself in this particular fermentation setting and learn the microbial rationale behind each fermentation step. Similar to Karin Knorr Cetina's endeavor to study the manufacture of laboratory knowledge, I focused on brewing protocols and the "practical reasoning" and "content" of brewers' grounds for taking certain actions and not others (1981, 22). I also analyzed "simultaneously *both* the concrete, "real" aspect and the aspect of semiosis and production in what we call scientific knowledge"

[4] I owe much of my thinking about space-making to Matthäus Rest, which stemmed from this seemingly mundane observation. It shifted my attention to the *what* of microbial processes to the *how* of microbial infrastructures.

[5] The interviews conducted then and there focused more on ethico-political questions about the human-microbe relationship and how to (continue to) live with microbes in uncertain times. Since the focus of this paper is on brewing *practices*, in which I also partook as an apprentice brewer, I am citing practice-based data instead of interviews, discourses, or texts.

(Haraway 1991, 195, original emphasis). Rather than cordon myself off to conduct participant observation from afar, I gathered data *as* a practicing apprentice brewer and gathered information (across my body) to make sense of sake-related microbes *in-situ*. By doing the work of fermentation, I could engage with the spaces, its tools, and their practices firsthand and frequently. This allowed me to participate in knowledge-making practices while studying their effects in real-time.

I focused on the practices of fermentation in experiential terms to examine the relationship between epistemic questions of how one comes to know microbes in a given environment and what those microbes are. Following Annemarie Mol's term of praxiography, I emphasized "the practicalities of *doing*" (2002, 31, original emphasis) within a constellation of brewing spaces, tools, and beings. The term stems from Mol's studies about how atherosclerosis articulates with many bodies to enact itself, with the assertion that the disease is "never alone," attaching to bodies, procedures, and mediated technologies to make itself known in a hospital setting. Methodologically, Mol describes how "an ethnographer/praxiographer [. . .] takes notice of the techniques that make things visible, audible, tangible, knowable" (ibid., 33), which makes the process simultaneously context-dependent (particular to here and now) and distributed (contingent upon the arrangement of things). As such, a praxiographic emphasis does not treat knowledge as solely inhering to knowing subjects, and instead "it locates knowledge primarily in activities, events, buildings, instruments, procedures, and so on" (ibid., 32). Praxiography thus complicates the subject-object divide (the notion that a social subject knows and a natural object is being known) to analyze how knowledge is emergent and only stabilized as truths by the assumptions that undergird them.

Compared to studying so-called macrobes like dogs (Haraway 2008), sheep (Law and Mol 2008), or fish (Lien and Law 2011), microbes are not necessarily somewhere "out there" to study. They live on our skin, inside our bodies, and everywhere else including the terrains, surfaces, and depths that make up "the environment" (e.g., walls, kitchen floors, forest floors, and ocean floors the world over). Thus, an added complexity to knowing microbes is that the "object" of study (microbes and their knowledges) inheres, at least in part, to the "knowing subject" (my person), without knowing how "my" microbes shape or are shaped by the research environment. With this in mind, it may be more appropriate to say that working as a researcher-and-practitioner was the *only* way that I could situate myself in the situatedness of microbial knowledges. Straddling the worlds of thinking-making-and-doing, I used an approach that suggests a form of deep inquiry that subsumes the differentiation between scientific knowing-why and practical knowing-how.[6] The repeated practices of fermentation helped to string together multiplicitous experiences with and about microbial knowing.

To make sense of microbial knowledge-making practices, I prioritized multispecies and multisensory details to identify what came to matter in knowing microbes. I modulated the ethnography with sensorial and spatial considerations, with emphasis on embodied (Probyn 2016, 16) and "emplaced"

[6] Research-creation and bioart already does this kind of tripartite thinking-making-doing. See for instance the oeuvre of Francois-Joseph Lapointe (2015) or WhiteFeather Hunter (2023). See also Hey, Hunter, and St-Hilaire (2019).

subjectivities (Pink 2009, 15) to situate my body—self who thinks and feels in relation to the microbial apparatuses I was studying. A sensory emphasis also afforded attention to my own ocular centric tendencies, heeding Haraway's caution that "all eyes, including our own organic ones, are active perceptual systems, building in translations and specific ways of seeing" (1991, 190, original emphasis). Touching, smelling, and tasting different microbial cues had me "grappling with unfamiliar sensoriums" of multiple species (Kirksey and Helmreich 2010, 565), which helped characterize my engagements while also nuancing bacterial versus fungal encounters. Combined, these sensibilities afforded me proximity and participation in the human and microbial worlds I wished to study, figuring and being configured by the spaces, tools, and practices of brewing.

While at the brewery, I learned that "*to know microbes*" requires one to know "*how to make spaces*" for only certain species to thrive. The next section elaborates on these space-making practices.

Space-Making at the Brewery: Sake Spaces, Tools, Practices

Sake is an alcoholic beverage made entirely of rice. Unlike most alcohols, sake is made up of three different fermentation processes. First, a fungal species (most predominantly of the *Aspergillus* genus) ferments rice into an enzyme-rich ingredient called *koji*; second, communities of bacteria and yeast ferment rice into a starter culture; and lastly, the koji and bacteria-laden starter culture are assembled with more rice to jumpstart the alcoholic fermentation process that mostly relies on yeast (i.e., *Saccharomyces cerevisiae*). These steps happen simultaneously to accommodate a production schedule of a sake business. This means that, at any given time, brewers are engaging in space-making practices.

I define space-making as the human practices (with brewers in this case) that configure environments to encourage certain microbes over others. As the name implies, it entails making spaces for the hope of particular microbes to emerge, which then calls upon additional practices that determine whether to adapt and shift the environment further. Because microbial lives run considerably shorter than human ones, these practices repeat frequently over time, eventually coalescing into a corpus of knowing. Characterized by specific, adaptive, and enduring practices, space-making remains in the present tense. It is a *gerund* that "focuses on the making, and asks us to tune into microbes as living entities in a state of becoming, rather than as fixed and stable, even invisible" (Sariola 2021b, 29). It refers to what is done now, for the time being, in anticipation of microbes to come.

Below, I explain three instances of space-making: how brewers utilize the architecture to make spaces for koji spores to thrive, how brewers choose tools to make space for bacteria thrive, and how brewers clean as a perpetual form of space-making for future microbes.

But I must first give context to the main brewing space. All steps happen in the main brewhouse, which is the source of TH's microbes. That is, the microbes who ferment every aspect of sake live in the crevices and crannies of TH's main space (see Nishida 2021 on endogenous bacteria living in the brewhouse). Since no step entails "adding" microbes to a fermentation vat, the brewing tanks inside the brewhouse are kept open at the top, only loosely covered with mesh nets or wooden lids to keep out larger pieces of debris. For the brewers, the brewhouse is permeable, akin to the dynamicity of any living system. Working with this dynamicity, then, brewers selectively mobilize spaces and tools to create environments conducive to some, but not all, microbial labors.

Making the Fungal Ingredient Koji

A key ingredient to sake is called koji. It is a mold-based ferment. Making koji seems deceptively simple: sprinkle koji spores onto steamed rice.

Molds thrive in moist, damp environments. So, it follows that making koji requires warm, humid environments to propagate, but koji also has a sweet spot: too hot and they may go to spore, too cold and they fall dormant. As such, the koji-making room is the only enclosed space in the brewhouse to maintain the heat and humidity for cultivating a fungal-based koji. While electric heating can help maintain a constant *room* temperature, it is ultimately the brewers' responsibility to keep, adapt, monitor, and adjust the *koji's* temperature through space-making practices, and ultimately stay within the sweet spot.

The room's architecture provides material assistance. The room is made of wooden floors, walls, ceilings, and work surfaces. The materiality of wood modulates the humidity by wicking away moisture in ways that metal or plastic cannot. Half of the room is made up of one long worktable. Behind it are two long rectangular basins that resemble twin-size bedframes with their slats. Each basin has an array of small doors underneath the slats to provide more airflow from underneath. The room feels balmy to the human skin, like a sauna, and, compared to the rest of the frigid brewery, working inside the room can initially feel like a warm welcome. I emphasize "initially" here because sweat, the very human response to fungal environments, can feel cold when returning to the rest of the cool brewhouse. Making spaces, like matters of care (Puig de la Bellacasa 2011, 100), cannot be universalized across multiple species' needs.

Frustratingly, the heat of the room is both an advantage and a challenge because it is only sometimes desired. Growing koji is an exothermic process, meaning that it produces heat when it propagates. During the initial phase of growing koji, the goal is to hold onto heat to encourage the *Aspergillus* molds to spread throughout a batch of steamed rice. But the latter phase of koji-making quickly switches to cooling down the koji because the collective metabolism of a now-teeming *Aspergillus* can generate enough heat to self-destruct.[7] Thus, key to koji production is assessing its propagation state and knowing how to intervene.

Brewers make space for koji through material considerations. The textile apparatuses used to hold and carry in-progress koji are made of cotton and hemp, where the former is used to retain more heat, the latter used to release it. During the initial phase of holding heat and encouraging the spread of *Aspergillus*, thick cotton bundles up the in-progress koji, which are further wrapped in multiple layers of cotton blankets. In the latter phase, the koji is transferred to the slatted basin, lined with hemp to keep it from overheating. Sometimes one room has to hold multiple batches of koji at the same time, where one batch has to hold on heat (to propagate the mold), and another has to release heat (to keep it from going to spore). Changing the overall room's temperature might only help one batch, and not the other. Thus, it is up to the brewers' space-making practices to accommodate the differential thermal needs of multiple *Aspergillus* batches.

[7] Self-destruction is an admittedly human point of view. From the koji's perspective, they are proceeding to the next life phase of (re)producing the next generation elsewhere (i.e. by spore).

Over the three days it takes to make koji, the gerunds that brewers perform are: mixing in spores, piling into heaps, aerating in-progress koji, and measuring temperatures throughout the process to mentally chart the logarithmic growth pattern of fungal populations. They compare the temperatures from different sources, including multiple probes stuck into heaps of in-progress koji, the room's dry temperature, as well as its "felt" temperature (similar to the "feels like" temperature on weather reports). From these measurements, the brewers further collect data from their senses, including scent (e.g., for fruity or nutty smells as signs of esters) and taste (e.g., for signs of sweetness as indication of amylase activity). Enzymes are neither quantified nor enumerated. If rice is transformed into something as fragrant and tasty as the koji before them, this information suffices, for surely there are other pressing microbial needs outside of the koji room.

Architecture and materials matter when making koji because temperature and humidity matter for *Aspergillus* growth and enzyme development. Brewers know that koji-making is an exothermic process, which makes it susceptible to overheating. As a result, they know temperature and humidity thresholds and conduct multiple temperature readings to monitor when koji runs close to a dangerous temperature. In such an event, they intervene with space-making practices.

Choosing Tools to Start the Sake-Starters

The starter cultures for sake contain bacteria and yeast. Many contemporary breweries opt for blends curated by Brewer's Association of Japan (日本醸造協会), known for producing consistent flavors, with pre-determined temperatures and pre-measured concentrations for optimal metabolic output (that, eventually, become organoleptic tastes). But TH relies on endogenous microbes to make their starters. Doing so takes longer, *letting* species gather over time instead of pouring a vial with known microbes. Creating starters in this way acknowledges the diverse—if unpredictable—ecologies of microbial species.

To ensure robust starters, brewers must first cultivate a teeming population of bacteria before cultivating yeast into the same starter culture. To begin, rice, koji, and well water which are mixed, mashed, and left open, exposed to whichever species gets to the substrate-rich, yet-to-be-fermented starter first. This means that, without space-making practices, *any* microbe can enter the open vat. But, ideally, the starter culture becomes populated with acid-producing bacteria first, which helps lower the pH enough to ward off molds (a similar acidic warding-off phenomenon can be seen in *sour*dough[8] starters). Thus, brewers spend the initial weeks of starter-propagation making spaces that encourage bacteria—not yeast.

For instance, all tools for starting starters have duplicates, with one set labeled "with" and the other set "without." These labels delineate which set has touched—and thus very likely carry—yeasts, since tools can easily, inadvertently, and prematurely transfer yeasts from one starter to another. By using the "without" set of tools for starter cultures in its early stages, brewers can "delay" the yeasts for as long as

[8] Italics are used to emphasize the acid-producing bacteria who enact this warding-off phenomenon.

possible.[9] In so doing, a variety of acid-producing bacteria congregate inside the starter, and this biodiversity out-competes other species.

To detect the transition from a bacteria-only starter to a starter with a low-enough pH for yeasts to withstand and gather anyway, the brewers use visual cues. They look for a ring of small, foam-like bubbles towards the center of the in-progress starter which, when poured, shows a different viscosity as a result of yeast activity. Small bubbles start to form as well. As soon as the brewers detect yeast, they switch to the "with" set of tools for everything from temperature probes, to mashing poles for aerating starters, to ladles for taking samples.

Tools alone do not create robust starters. Acid-producing bacteria thrive better at lower temperatures (i.e., 4–10 degrees Celsius compared to the 20–25 degrees that yeasts are most active), so the trick is to lower the starter culture's temperature for as long as possible to create biodiverse and dense populations of acid-producing bacteria. That said, like the preceding koji example, more than one batch occupies the starter-making space, so the ambient temperature may not be the desired temperature. Some starters might be in its early phases needing bacteria (and thus need cooler temperatures) whereas others might be in its later phases needing yeast (and thus need warmer temperatures). To make certain starters conducive for bacteria and others for yeast, the brewers use the equivalent of a hot water bottle or ice-cans to create micro-climates for the immediate microbial vicinity. Indirectly, then, brewers adjust the microbial composition of these starters by changing the temperature inside the open tanks.

Knowing which tools to use for bacteria, for yeast, and at which stage affects whether or not the brewers can develop robust starters. At times, brewers make spaces that encourage bacteria, at other times yeast. Order comes to matter, which is why they pay attention to bacteria-promoting temperatures versus yeast-promoting temperatures. The brewers may not know which exact microbes are there, but precision is moot for them when their apparatuses show enough information to proceed to the next steps of fermenting.

Cleaning: The Practice of Attending to Microbial Futures

Space-making is most evident in TH's cleaning practices, in which handling the tools—made of wood, cotton, bamboo, and hemp—necessitate more hands-on attention compared to wiping down stainless-steel vats or other non-porous surfaces with anthropogenic substances. Soaps and chemical sanitizers, while easier to deploy, are difficult to remove because the pores and crevices of surfaces and tools that help endogenous microbes persist are the same pores in which chemical residues can linger and affect future iterations of sake brewing. So, the brewers do not use any chemical agents. Rather the brewers' cleaning practices account for what materials to use now, how to do so, and to adapt their modes of cleaning for fermentations yet to come.

[9] The risk of yeast "arriving" too early is that they "peak" too early in the alcoholic fermentation process as well, which results in unfermented rice starches and thus a waste of koji and the time, labor, resources that went into assembling the tank.

Like any brewing context, cleaning and sanitation are crucial for TH, but the brewery shifts how they clean. For instance, TH uses steam to selectively sterilize wooden tools or use boiling water on enamel and plastic. (This is the case for the "without" set of tools, to keep the set without yeasts.) Most microbes die when they come into contact with steaming/boiling temperatures, with the exception that mold spores (like koji) can go dormant and await conditions that are more favorable. But, because koji requires warm and humid environments, a rogue spore in the rest of the brewhouse *would remain* dormant. In other words, the logic of cleaning is not to eradicate all microbes but to favor select microbes to ferment rice into sake at any given time-and-space. In turn, space-making practices acknowledge the partiality and limitation of cleaning-as-elimination in a brewhouse teeming with microbes—and, this *teeming* quality is precisely what the future of the brewery needs.

Therefore, cleaning is space-making for future microbes yet-to-come. What could easily take a fraction of the time with chemicals instead relies on proverbial elbow grease and care. As such, the ritualized cleaning might be better reframed as the long-game for working with/in inevitably microbial spaces instead of a reset or return to some pristine non-microbial space. Cleaning, then, is not just a human endeavor but a deliberate moment of thinking through the future of human-microbe encounters.

In a way, the brewers are fermenting the space: since one cannot know the composition or location of microbes, one must clean and care for microbial spaces. In contrast, a finer degree of knowing underwrites a narrative predicated on causality where precision can over-determine which microbes are worth keeping alive (i.e., eradicate these "bad" microbes to let the "good" ones live). Broadly speaking, brewers clean to make space for *all microbes* regardless of their functional value and, as a result, all subsequent space-making efforts must make spaces for certain species, at certain steps, in certain sequences, in certain spaces.

Knowing Enough and its Temporalities

The brewery forgoes a mechanistic approach to fermentation—which might focus on microbial identities, microbial control, and the biochemical transformations they promise—and instead holds a more holistic view of fermentation where brewers are tasked with continually making spaces conducive for sake-microbes to keep doing the work of fermentation. Of course, "sake-making microbes" are not just one species nor collectively thrive in one kind of environment. The examples above show three categories of species (a mold spore, acid-producing bacteria, and yeast) in different niches (one warm and humid, one cool), which point to the need for brewers to enact different practices to attend to differential needs. Through space-making, brewers continually use *specific* tools (e.g., breathable fabrics, tools "with" and "without" yeast contact, steam), in an *adaptive* manner to continually configure spaces *over time*.

I argue that TH's approach foregoes knowing microbes in full, refraining from apparatuses that offer precision or high specificity. Like the cleaning example above, the brewers prepare microbial environments in anticipation of the next encounter—that is, they *know* microbes are present without knowing which are exactly, and this is enough to proceed with space-making as praxis. They do not know in advance which particular microbes will come, just that they might, on condition of their own doing (i.e., space-making).

I see an eco-fungal connection, whereby the space-making practices of brewers parallel the descriptions of efforts to regenerate satoyama forests. Elaine Gan and Anna Tsing (2018) describe how

human planning does not produce mushrooms; coordinations within more-than-human assemblages do. Matsutake grow in satoyama forests neither fully from happenstance nor from manmade orchestration, but due to key interventions, including the (space-making) practices of satoyama revivalists.

According to Gan and Tsing, these revivalists make spaces for fungal growth with specific tasks like harvesting bamboo shoots to mitigate its spread in the forests where red pines (matsutake's sole symbiont) would otherwise take root. These satoyama revivalists, like the brewers, shed their expectations about control to instead develop specific, adaptive, and long-term familiarity with more-than-human entities (pines, oaks, mushrooms). They describe how "[t]he ecological coordinations of the satoyama are unplanned. Through working with and around each other over a long period of time, pines, matsutake, oaks, and farmers have developed [. . .] the dynamics of livability" (ibid., 132–133). The revivalists make spaces for matsutake to thrive through indirect practices and apparatuses of coordination instead of control.

Similarly, for the brewers, relinquishing control is partly due to the recognition that humans and microbes are not the only participants in sake assemblages. Sacks of rice, well water, hoses, pails, brushes, beams, hooks, and tanks do not just occupy the fermentative environment. These entities also configure the space with their multiple, compounding affordances. Besides being objects used for fermenting practices—like in mixing, pouring, aerating, ladling, and so forth—these entities also serve as surfaces that harbor and carry microbes. To take samples from all objects in the brewhouse and analyze them repeatedly to ascertain which exact microbes are where, would take time, attention, and resources away from what the brewers already (need to) do to stay coordinated with the various microbes dwelling inside the brewhouse. Instead, to enact space-making practices allows them to continually know enough about what is happening: that microbes, *generally* speaking, are gathering.

This general activity matters more to them than the specificity of which microbes are active. In many instances, the brewers rely on temperature to understand that any thermal increase is an increase in microbial activity. However, temperature does not indicate *which* microbe is active, just that they are in a state of microbial activity. Sometimes, sensory tools can aid in differentiating which microbes are active (e.g., they can taste the presence of acid-producing bacteria), but such tools do not offer high levels of specificity (e.g., taste alone cannot parse the activity of *Leuconostoc* species versus *Lactobacillus* species). Since space-making sets up configurations of spaces and tools in advance, when they take measurements later (i.e. as temperature readings), they continue with the knowledge that whatever activity is taking place is most likely going to be the targeted microbe then/there for whom *they, the brewers*, set up the space. And, if not, *they, the brewers*, adjust once more. The temperature readings, then, measure thermal activity as a proxy for metabolic activity,[10] and this metabolic activity is a sign *enough* that a desired fermentation process is taking place.

[10] I owe the notion of proxy to Salla Sariola, who argues that we often know microbes through something else, where that "something else" stands in for the microbe. See introduction, of this issue (Cañada, Sariola, and Rest 2025).

The brewers do not know when and how these microbes mobilize and become active, except for that their entire brewing praxis sets up the conditions that favor sake-making microbes, and have done so for centuries. They know that "good" microbes cannot be kept in containment, at least not inside any of the tanks left open to the sprawling brewhouse, and by the same logic, brewers also forgo trying to block microbes from the "outside" of tanks. They reject optimizing their process on the basis of "good" and "bad" microbes because the time needed to assess the utility or identity of microbes would take time and effort away from brewers who could practice space-making.

Because microbes are always present, their ubiquity means that the potential for fermentation to proceed is also ever-present; so, *how* the brewers take up space, and make space for fermentation. Microbes affect their practices, which in turn influences which microbes will be enabled and thus what kind of sake results. The micro-decisions along the way are not devoid of a scientific lexicon (e.g., some brewers describe fermentation steps in terms of enzymatic activity or families of microbes) but the brewers do not prioritize or solely rely on this information for determining next steps.

In fact, in delegating the leadership roles at the brewery, one brewer is tasked with chemically analyzing samples of in-progress sake once or twice per day. Each sample is analyzed to measure pH, Brix (the amount of solids dissolved in a liquid), and Baumé (the density of various liquids), but, crucially, this analysis takes place *after* the ingredients have been assembled. This may be because, in the cool of the brewhouse, heat dissipates quickly so waiting for chemical analysis may complicate heat-sensitive tasks such as koji propagation. In addition, each sample analyzed is but a snapshot in time: of the microbes then, in the place there, which may no longer be there by the time the results are reported. In other words, there is a primacy placed on *knowing enough* to act in accordance with the microbes of here-and-now in space-making, and, as a result, information derived from (scientific) analysis is relegated for the time being. It is a form of knowing based on open-ended inquiry, not mastery, where primacy is placed more on *in-the-moment* adaptiveness rather than control.

Knowing How, Knowing Why, Knowing as Inquiry, Inquiry as Method

Since microbes remain ambiguous and everything is interdependent and therefore dynamic, the brewers can only know for certain the proactive work that *they, themselves* contribute. What matters is that microbes are kept alive and active in some capacity, because, at least then, the brewers can intervene in ways they already know how. By intervening on *the space* versus the species, the brewers can care for microbes that "can leave open the detection of specific needs for caring in each situation, instead of presupposing there is only one way of caring" (Puig de la Bellacasa 2011, 96). Their care is specific and anticipatory in a way that "requires knowledge and curiosity regarding the needs of an "other"—human or not—and these become possible by refusing objectification" (ibid., 98). The brewers refuse to treat the invisible microbes as objects to manage and instead maintain an openness to how and when they might meet—and make spaces that anticipate future encounters with particular sake-microbes.

The brewer/microbe relations at TH follow a logic of care instead of choice, such that the brewers do not distance themselves in a neutral manner but instead intervene directly on microbial matters. Choice has a linear rhetoric. Calling upon doctor/patient relations in diabetes care, Mol (2008) explains how the

logic of choice unfolds so that, to paraphrase: facts are stated, values are weighed, then action is taken; data are managed, and plans are implemented. But, she argues that care complicates linearity:

> There is no single, crucial moment when all relevant fact-values are available. Problems emerge and as they are tackled new problems arise [...]. And when something unexpected turns up, it has to be integrated with everything else (ibid., 54).

There is no single moment when the brewers can make an absolute call on the state of the brewhouse's microbes. There are simply too many, with life cycles too short and staggered to have any totality of knowing.

In spite, or because of this seeming limitation, the brewers account for as many variables as they can, and in relation to one another. In other words, how are these species doing, in this batch, in relation to our ideal timeline for using this ingredient in the long-run of brewing this season and hereafter? Isolating any one of these variables detracts from the whole synchrony of microbial labor inside the brewhouse. Space-making allows the brewers to practice a form of tinkering where they can still engage with microbes-there-for-the-time-being as a provisional data point, to then revisit later, and adjust accordingly:

> There is always something to improve. Even idealised practice is not ideal. It is a matter of trying things out and of being willing to revisit what has been done before. There is always something that fails. Try again, adjust, improve. (ibid., 56)

The brewers do not "know microbes" per se; it would be more accurate to say that they know what kind of spaces they create relative to the target microbes then and there—which allows them to accumulate partial knowledges over time.

To determine "what is happening microbially" in each step, brewers come to know microbes through tools (e.g. thermometers, noses) and configurations (e.g. architectures, sequences) of spaces, beings, and things. Combined with space-making practices, they shape and are shaped by the measurements they conduct, as part of the microbial apparatuses of TH. As Schrader (2023) reminds us, a measurement is itself an intra-action, citing Barad's definition of "the mutual constitution of entangled agencies" (2007, 33). Applied to the brewery, a temperature reading (sign of microbial agency) is co-constituted with the agency of the brewer-with-thermometer who measures. Who these microbes *are* (i.e., the microbes best suited to make a particular sake ingredient) are not predetermined so much as they become the response to an environment that brewers setup and subsequently measure. By making themselves measurable and thus known, the sake-making microbes demonstrate the "boundary-drawing practices—specific material (re)configurings of the world—which come to matter" (ibid., 140). The repeated practices of space-making reconfigure microbial worlds.

Knowing microbial worlds in fermentation is often contrasted as knowing how ("fermentation is an art") versus knowing why ("fermentation is a science"). In analyzing the different approaches to cheesemaking, Heather Paxson describes an incident in a cheesemaking class, for which she distinguishes scientific knowing-why versus traditions of knowing-how. One of her interlocutors explains how certain knowledge about cheesemaking (like the length of time needed for the curds to set) is "a matter of knowing-how for which one must *develop a feel*; it is another kind of qualitative calculation" (2013, 146, emphasis added). The feel of microbial transformation in cheesemaking (and sake-brewing) is a particular form of

tacit knowledge that develops over time and repetition. To "develop a feel" is to accumulate the sensory recall in one's body into a knowledge corpus.

For the brewers, the *why* of sake falls to a secondary concern and only becomes an issue if and when something surprising should arise. Their primary modus is to continually attend to *how* the microbes are active, *how* to anticipate their next activities, and *how* to interpret measurements like temperature readings. Or, thought differently, the why of temperature is a straightforward answer for the brewers: changes in temperature are a sign of microbial metabolism and liveliness. They already know this. But precise accounts of which microbes are active fall out of favor when trying to determine what to do in the meantime, so the knowledges that brewers gather (like temperature measurements) become useful only if they allow brewers to anticipate—and make space for—the next microbial move.

Throughout sake fermentation, the brewers seek out key information—whether from practices, from measurements, or from their sensory recall—to situate microbial knowledge in the here-and-now and assess what to do next, in anticipation of next brewing steps and the microbes needed for said steps. Although categorizations such as "brewery vs. laboratory" or "brewer vs. scientist" may bolster the binary of "practitioner vs. researcher," making sense of microbes happens at the nexus of tinkering with objects, be they microscopes, temperature probes, slatted basins, barrels, hoses, or otherwise. Karin Knorr Cetina calls these objects "enhanced agents" in the laboratory that are arranged "so as to fit a particular emerging order of self-other-things, a particular ethnomethodology of a phenomenal field" (1992, 119). In an analogous manner, microbial knowledge(s) emerge from the way brewers' space-making arranges these enhanced agents. Knorr Cetina continues, stating that, "[i]n the laboratory, scientists are *'methods' of going about inquiry*; they are part of a field's research strategy and a technical device in the production of knowledge" (ibid., emphasis added). Thought of in this way, researcher and practitioner are not dissimilar in their inquiry about what microbes are doing.

Both researcher and practitioner become "devices" equally carrying "*repositories of unconscious experience* whose responsibility it is to develop an embodied sense for resolving certain problem situations" (ibid., original emphasis). Whether running a gel electrophoresis (and knowing when to stop) or trying to cool down overheating koji (without cooling it too much for it to go dormant), both figures rely on their repertoire of tacit and cumulative knowledge which resides in their bodies. For both researcher and practitioner, repeated experiments/batches form the basis of inquiry, asking what will happen this time? And the next? Throughout this study, I have called upon fermentation as a *method of inquiry*, partaking in the knowledge-making practices of microbes as I study them, acting myself as a "device" in the microbial apparatuses of TH.

Growing research in STS attends to knowing microbes through a variety of methodologies and across vast sectors/habitats, ranging from the studying the science from within (Schrader 2010, 2017; Benezra 2020; Ng 2023), to ethnographic accounts (Paxson 2013; Delgado 2024), to theorizing human-microbe relations in the everyday (Whiteley and Bencard 2017; Brives, Rest, and Sariola 2021). With already a sensitivity towards "making and doing," STS has the capacity to engage with making and doing as a mode of data collection and not just a mode of diversifying how knowledge can be expressed or in which direction (Downey and Zuiderent-Jerak 2021). As a longstanding practice, fermentation comes to know microbes across the embodied senses, multiple species, and, an environment where biodiverse microbes teem and

shift over time. Building on and diffracting extant practices like fermentation may offer new, situated insights for knowing microbes otherwise.

Conclusion

This paper examined the configurations of how brewers come to know microbial life, focusing on three particular space-making practices: making a fungal ingredient, choosing tools to start starter cultures, and cleaning protocols. Space-making encourages some microbes and not others; these practices proactively and continually make spaces for certain microbes by attending to the metabolic, reproductive needs of certain species. Since microbes are ubiquitous, variable, and unpredictable, brewers privilege knowing enough to set up subsequent space-making practices over knowing exactly why a phenomenon takes place. For the brewers, knowing enough keeps open the possibility of seeing microbes as lively forces to work with, reckon with, and anticipate in recurring encounters of fermentation. Rather than react with capitalist notions of optimization, the work dynamic between human and microbe evades a modernist schema of control because microbes are not reduced to manageable objects.

By showing the practices in fermentation, this paper theorized space-making as a mode of microbial knowledge production, with hopes that it can be applied elsewhere in (especially environmental) microbes. As an empirical example, the analysis of brewers show how space-making (a) engages with lively entities and adapts; (b) spans time, both present and future, as a series of practices; (c) accounts for the specificities that care demands; and (d) holds the tensions between time spent versus specificity of knowing. As a conceptual term, space-making has the potential to nuance other microbial processes (e.g., composting, bioremediation, bioengineering) without over-determining what microbes are in each of these phenomena. Space-making also complicates what constitutes microbial expertise. Scientific apparatuses are not the sole arbiters for accessing microbial knowledge, which has ramifications for future social scientific inquiry involving microbes, as well as adjacent fields (e.g., bioart, medical humanities) for whom "knowing microbes" has been seen as a bottleneck.

This paper also analyzed fermentation as a method of research. In addition to diversifying non-scientific apparatuses for knowing microbes, this paper contributes undoing the dichotomy of scientific versus traditional knowing or disciplinary, academic, or university thinking that separates "research" from "practice." This paper proposes fermentation as a diffractive methodology that, *by doing the work firsthand*, and only so, one comes to understand the differences—materially, spatially, microbially, practically—that come to matter, for whom, and when. As such, fermentation is not simply a metaphor for understanding human-microbe relations or a representationalist account that reflects western/non-western paradigms of microbial knowledge-making.[11] As a non-laboratory method, fermentation provides steps for learning which microbial differences matter.

[11] The caution of extraction out of informants/communities still applies, especially in the context of neoliberal models of higher education.

The findings from this paper do not stop with "what happened at the brewery" during some episode of praxiographic research. In many ways this paper adds to the momentum of developing more and better approaches to studying the microbes who compose and decompose our very being and environments. As with my central argument—that space-making for microbes allows us to hold the tension of not-knowing microbes but knowing them enough—this paper offers epistemic inroads for configuring multiple, partial, and diverse ways of knowing (microbes). It is my hope that knowing enough and doing something anyway keeps open other roads for more microbial knowledges to come.

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References

Barad, Karen. 2003. "Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter." *Signs* 28(3): 801–831. https://doi.org/10.1086/345321.

———. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press.

Benezra, Amber. 2020. "Race in the Microbiome." *Science, Technology, & Human Values* 45(5): 877–902. https://doi.org/10.1177/0162243920911998.

Brives, Charlotte, Matthäus Rest, and Salla Sariola, eds. 2021. *With Microbes*. Manchester: Mattering Press.

Cañada, Jose A., Salla Sariola, and Matthäus Rest. 2025. "Situating Microbes Within Complex Ecologies." *Engaging Science, Technology, and Society* 11(1): 5–20. https://doi.org/10.17351/ests2023.2735.

Delgado, Ana. 2024. "Microbial Extractions: Sequence-based Bioprospecting, Augmented Promises, and Elusive Politics." *Science, Technology, & Human Values* 49(3): 443–471. https://doi.org/10.1177/01622439211055693.

Downey, Gary Lee, and Teun Zuiderent-Jerak, eds. 2021. *Making & Doing: Activating STS Through Knowledge Expression and Travel*. Cambridge, MA: MIT Press. https://doi.org/10.7551/mitpress/11310.001.0001.

Gan, Elaine, and Anna Tsing. 2018. "How Things Hold: A Diagram of Coordination in a Satoyama Forest." *Social Analysis* 62(4): 102–45. https://doi.org/10.3167/sa.2018.620406.

Haraway, Donna J. 1991. *Simians, Cyborgs, and Women: The Reinvention of Nature*. New York: Routledge.

———. 2008. *When Species Meet*. Minneapolis: University of Minnesota Press.

Helmreich, Stefan. 2007. "Blue-green Capital, Biotechnological Circulation and an Oceanic Imaginary: A Critique of Biopolitical Economy." *BioSocieties* 2(3): 287–302. http://doi.org/10.1017/S1745855207005753.

Herrera, César E. Giraldo. 2018. *Microbes and Other Shamanic Beings*. London: Palgrave Macmillan.

Hey, Maya. 2021. "Attunement and Multispecies Communication in Fermentation." *Feminist Philosophy Quarterly* 7(3): 1–24. https://doi.org/10.5206/fpq/2021.3.10846.

———. Forthcoming. Ongoing Song: Fermentation and Living with Microbes. Minneapolis: University of Minnesota Press.

———, WhiteFeather Hunter, and Emilie St-Hilaire. 2019. "Horizontal Exchange, Relations, and Resistance in Bioart and Practice-based Research." *Journal international de bioéthique et d'éthique des sciences* 30(4): 69–89. https://doi.org/10.3917/jibes.304.0069.

Hunter, WhiteFeather. 2023. "Mooncalf Menstrual Meat (MMM)." Continuum: Journal of Media and Cultural Studies 37(5): 576–594. https://doi.org/10.1080/10304312.2023.2231666.

Kirksey, Eben, and Stefan Helmreich. 2010. "The Emergence of Multispecies Ethnography." *Cultural Anthropology* 25(4): 545–76. https://doi.org/10.1111/j.1548-1360.2010.01069.x.

Knorr-Cetina, Karin D. 1981. *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science*. Oxford and New York: Pergamon Press.

———. 1992. "The Couch, the Cathedral, and the Laboratory: On the Relationship between Experiment and Laboratory Science." In *Science as Practice and Culture*, edited by Andrew Pickering. Chicago: University of Chicago Press.

Lane, Nick. 2015. "The Unseen World: Reflections on Leeuwenhoek (1677) 'Concerning Little Animals.'" *Philosophical Transactions of the Royal Society B: Biological Sciences* 370(1666): 1–10. https://doi.org/10.1098/rstb.2014.0344.

Lapointe, Francois-Joseph. 2015. "On the Role of Experimentation in Art (and Science)." *Journal of the New Media Caucus* 11(3). https://median.newmediacaucus.org/research-creation-explorations/6095-2/.

Latour, Bruno. 1993. *The Pasteurization of France*. Translated by Alan Sheridan and John Law. Cambridge: Harvard University Press.

Law, John, and Annemarie Mol. 2008. "The Actor-Enacted: Cumbrian Sheep in 2001." In *Material Agency: Towards a Non-Anthropocentric Approach*, edited by Carl Knappett and Lambros Malafouris. New York: Springer.

Lien, Marianne Elisabeth, and John Law. 2011. "'Emergent Aliens': On Salmon, Nature, and Their Enactment." *Ethnos: Journal of Anthropology* 76(1): 65–87. https://doi.org/10.1080/00141844.2010.549946.

Lee, Victoria. 2021. *The Arts of the Microbial World: Fermentation Science in Twentieth-Century Japan*. Chicago: The University of Chicago Press.

McConnell, Molly. 2023. "Starting to Care: Making Place with Microbes." *Cultural Geographies* 30(4): 525–537. https://doi.org/10.1177/14744740231158604.

Mol, Annemarie. 2002. *The Body Multiple: Ontology in Medical Practice*. Science and Cultural Theory Series. Durham: Duke University Press. https://doi.org/10.1215/9780822384151.

———. 2008. *The Logic of Care: Health and the Problem of Patient Choice*. London: Routledge.

Ng, Alicia. 2023. "Transforming Toxic Materialities: Microbes in Anthropogenically Polluted Soils." *Theory, Culture & Society* 42(1): 37–52. https://doi.org/10.1177/02632764231187580.

Nishida, Hiromi. 2021. "Sake Brewing and Bacteria Inhabiting Sake Breweries." *Frontiers in Microbiology* 12: 1–3. https://doi.org/10.3389/fmicb.2021.602380.

Paxson, Heather. 2013. *The Life of Cheese: Crafting Food and Value in America*. Berkeley: University of California Press.

Pink, Sarah. 2009. *Doing Sensory Ethnography*. London, Thousand Oaks, CA: Sage Publications.

Probyn, Elspeth. 2016. *Eating the Ocean*. Durham: Duke University Press.

Puig de la Bellacasa, Maria. 2011. "Matters of Care in Technoscience: Assembling Neglected Things." *Social Studies of Science* 41(1): 85–106. https://doi.org/10.1177/0306312710380301.

Raffaetà, Roberta. 2023. *Metagenomic Futures: How Microbiome Research Is Reconfiguring Health and What It Means to Be Human*. London: Routledge.

Rest, Matthäus. 2017. "Incubator, or, Sugar and Light: The Preconditions of Fermentation and Culture." *Fieldsights: Society for Cultural Anthropology*, Theorizing the Contemporary Series. Published December 19, 2017. Accessed July 1, 2021. https://culanth.org/fieldsights/our-electric-sustenance.

Sariola, Salla. 2021a. "Fermentation in Post-Antibiotic Worlds: Tuning in to Sourdough Workshops in Finland." *Current Anthropology* 62(S24): S387–S398. https://doi.org/10.1086/715208.

———. 2021b. "G is for Gerund." In *musings*, edited by Maya Hey, 28–29. Montreal: Radish Press. http://www.foodfeminismfermentation.com/p/musings-2019-edition.html.

Schrader, Astrid. 2010. "Responding to *Pfiesteria piscicida* (The Fish Killer) Phantomatic Ontologies, Indeterminacy, and Responsibility in Toxic Microbiology." *Social Studies of Science* 40(2): 275–306. https://doi.org/10.1177/0306312709344902.

———. 2017. "Microbial Suicide: Towards a Less Anthropocentric Ontology of Life and Death." *Body & Society* 23(3): 48–74. https://doi.org/10.1177/1357034X17716523.

——. 2023. “Diffraction as Cross-Disciplinary Methodology between Science and Arts.” In *Diffracting New Materialisms: Emerging Methods in Artistic Research and Higher Education*, edited by Annouchka Bayley and JJ. Chan, 15–40. London: Palgrave Macmillan.

Whiteley, Louise, and Adam Bencard, cur. 2017. “Mind the Gut.” Exhibit, Medical Museion, Copenhagen. Accessed May 20, 2025. https://www.museion.ku.dk/en/mind-the-gut__/.