Chapter 14

Sweetness, Power, Yeasts and Entomo-terroir

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Yeasts are single-celled fungi. They are essential components of the modern world, ours and theirs, and yet their stories are hidden. Their consequences often take centre stage, but they themselves are rarely featured, whether in history, art, or even science. This absence has taken on new importance as it is realized that some yeast species may have begun to go extinct. These yeasts are threatened, of all things, by the declines in insect populations and, of course, indirectly and directly, by us. But this is the end of the story – let us start a little earlier.

Before

In the beginning, before humans evolved, before farms were planted, yeasts lived quiet lives immersed in the small patches of sweet things that can be found in nature – the nectar in the cups of flowers, the sap that leaks from oak trees, the honeydew that pours from aphids and scale insects, the flecks of sugar on oak leaves. In each of these bits of sweetness, the yeast consumed sugars. As waste, they exhaled carbon dioxide and excreted alcohol. Yeasts thrive on sugar. For most species, it is their ancient necessity. Yet, this necessity poses a challenge. The yeasts must find the sugar in the first place. They must find sugar even though they lack legs and wings, and even though, unlike bacteria, they do not readily become airborne. From the perspective of yeasts, all of the patches of sugar in the world, from

those on jungle leaves to those inside the most delicate tundra flowers, are remote. They are perfect and delectable and yet hard to come by; islands in a sugarless sea.[1]

Eventually, some yeast species evolved a way around this problem of travel. They evolved the ability to produce, when eating sugar, aromas that attract insects. Different yeasts produce different aromas and attract different insects. Some yeasts call to bees. Others put out their aromas, like a hitchhiker's thumb, to call for wasps – but not just any wasp, specific wasps. The yeast *Saccharomyces cerevisiae*, for instance, appears particularly predisposed to call to social wasps of the genus *Polistes*, paper wasps.[2] Each group of sugar-feeding insects, and in some cases even each species of sugar-feeding insect, seems to carry its own characteristic portfolio of yeasts. They take these yeasts with them as they pursue sweetness; they have carried them from one delicacy to another across months, seasons, years, and millennia.[3]

Most yeasts thrive on the sugars produced by plants – in nectar, in fruits, and on their leaves – but not all. Some yeasts grow instead from the sugars of the dead, the sweetness of animal bodies. But death, like flowers, is not everywhere. To find the dead, these yeasts ride in and on the bodies of carrion beetles. The carrion beetles carry the yeasts to the dead, whether it be dead mice or dead people. The beetles then strip the dead of their fur, roll their muscle into a ball, inoculate the ball with yeast and antibacterial compounds, bury the ball and lay their eggs near to the ball. Once planted by the beetles, the yeast begins to slowly eat the buried flesh, but, as they do, they also ward off other microbes, especially bacteria. As a result, when the beetles' babies hatch from their eggs and crawl to the ball of flesh, it has been fermented in such a way as to make it safe and delicious.[4]

Beetles benefit from their relationships with yeasts. But they are not the only such beneficiary. Wasps and the bees sometimes, and perhaps often, use the aromas of yeasts to find patches of sugars that they might otherwise have missed, patches of sugar in which (thanks to the alcohol produced by the yeast) pathogens are unlikely to be present. Like barflies they wing their way towards the rewarding aroma of fermentation.

Sex and Winter

Yeasts have needs, of course, beyond transportation and food. They need a way to survive in the times when food is scarce (such as winter), and they need a place to have sex. Here too, the insects can oblige. In the winter, some yeasts survive inside the bodies of the subset of insects that live more than one year. They wait there, patiently, until spring. As for sex, it

appears to be especially likely to occur inside those same insects (or, in some cases, after having passed through insects). This sex inside insects is, recent studies have shown, particularly likely to be promiscuous. Different strains mate and so too, even, do different species. Inside a wasp, hybrids are made.[5]

Humans

Ancient humans evolved around 1.9 million years ago. At some point those ancient humans began to leave out some of their food in containers.[6] Wasps and bees came to the food and left, inadvertently, their yeasts. The food rotted. The food bubbled. The food fermented. At first in Africa and then elsewhere, ancient humans and then modern humans would come to control this rotting, bubbling, fermentation. They could use it to their advantage. Fruits, when fermented, yielded alcohol and new flavours. Roots, when fermented, became more palatable and flavourful. Meat, when fermented, could be stored, for weeks, months or even longer. No one knew that the agent of this fermentation was a fungus, much less a yeast, and yet the biological consequences of this yeast's metabolism were known. They could be smelled and tasted and remembered. They were not depicted and yet the foods and drinks they helped to engender were a kind of art, an art that in some cultures came to be holy. In Christianity, for example, the body of Christ is represented as leavened communion bread, the blood of Christ as fermented communion wine.

No precise tally exists, but it appears that hundreds and perhaps thousands of ancient and modern human cultures independently found ways to ferment foods. Each of these foods attracted different insects and were colonized by different yeasts. Some meat, for instance, was colonized by the yeast used by carrion beetles;[7] the yeast protected the meat gathered by people, just as it had protected meat gathered by the beetles. Fermented fruits attracted sugar-loving yeasts. But there was a little more to these twisting, tangling, rotting relationships.

Before humans, the story of yeasts and insects had unfolded in different places independently. It began tens of millions of years ago, and so evolved in separate directions on each continent or island, and even in one habitat relative to another. There are yeasts, for example, found riding in only one kind of insect on one Hawaiian island.[8] Similarly unique local yeasts and yeast–insect relationships exist or existed all around the world. As a result, when the first human fermenters began to rely on yeasts, they relied on and began to shape the evolution of different yeasts in different places.

Just Before Agriculture

At some point before agriculture, people in and around China and the Fertile Crescent began to rely more and more on fermentation.[9] As they did, they began to feed the yeasts on which they relied with ever larger quantities of sugars. They did this by gathering grains in baskets. They offered these baskets of food to the yeasts, the way one would offer gifts to the gods. Where necessary, they even treated the grains so that they would be easier for the yeasts to eat. They mashed them. They malted them. They added dates to them. They worked hard to prepare better meals for the yeasts and the other microbes in their fermentations so as to facilitate the transformation, a kind of rebirth, that they hoped would occur.

During this period, something new was happening. In China and the Fertile Crescent, and probably also in other places, humans were beginning to more fully take over the role of the insect. The humans carried the yeasts on their hands, in their bodies and in their vessels, from one place to another. They carried them while riding horses. They carried them while in ships. They carried them while walking in groups from one village to another. As this was occurring, humans were no more aware of their role as vectors of the yeasts than were the wasps.

With Agriculture

The benefits yeasts provide to insects are varied and depend on the context in which a particular yeast is found, as well as on the details of the biology of the insect itself. The benefits yeasts were providing to humans would also come to be varied. Yeasts helped to store food (by preventing food spoilage bacteria from growing) and to make unsafe drinking water safe (by killing the pathogens in the water with alcohol). Yeasts made unpalatable foods, such as some roots, not only palatable but delicious. Yeasts leavened bread. Yeasts, for humans, enriched the culinary world. But they also did something else – they produced alcohol. Thanks to obscure details of the machinery of their brains, humans are pleased by alcohol. They can become addicted to alcohol. In drinking alcohol, they want more alcohol. To produce more alcohol, they need to grow more grains or fruits to feed more yeasts. Agriculture, it has been repeatedly argued, emerged in part in order to produce enough food not for humans, but instead for yeasts; enough food for the yeasts so that the yeasts might provide something in return: alcohol.[10]

In the context of the scaling up of the production of alcohol, a subset of kinds of yeasts was disproportionately likely to survive. The subset included

yeasts that grew quickly and yeasts that were tolerant of high concentrations of alcohol, and also produced high concentrations of alcohol. Such yeasts included the yeast *Saccharomyces cerevisiae*, brewer's yeast. Brewer's yeast is from a group of yeasts now thought to be native to China. Recent data suggest, and we hypothesize, that these yeasts from China spread, one fermentation at a time, to the Fertile Crescent. Human bodies and vessels carried them there, like wasp bodies but even more effectively.[11] Brewer's yeasts can live on bakers' hands.[12] Brewer's yeasts can live in beer drinkers' guts. From the Fertile Crescent, brewer's yeast began to spread with bakers, brewers, drinkers and eaters around the world. As it did, it became ever better at thriving in the conditions humans created, and ever better at outcompeting other yeasts. It became, inarguably, the single species on which humans were most predictably dependent: not wheat, not barley, not grapes, not rice, but brewer's yeast.

The Columbian Exchange

In 1492, Columbus set sail with three ships full of fermented foods and drinks. His ships carried fermented milk curds in the form of cheese. The cheese was alive with bacteria and fungi. His ships carried vinegar; the vinegar was alive with acetic acid bacteria and nematode worms (vinegar eels). His ships also carried salt-cured meat. That meat was covered with the bacteria and yeasts used in curing, such as the carrion beetle yeasts. And his ships included extraordinary quantities of wine, and hence the yeast and bacteria still living in the wine. The microbes from these foods and drinks appear to have spread everywhere in the ships, on the sailors and in the sailors, on the wood and in the wood. The ships were described as smelling 'frightfully of mules',[13] but must also have borne the aromas of yeasts and bacteria. This would have been true not only of Columbus's ships, but also the ships of each later wave of colonists. Consider the *Mayflower*, the ship that carried the pilgrims to New England. The *Mayflower* had been used, prior to its journey to North America, to carry wool from England to France, and wine from France to England. Ships that made this journey were called 'sweet ships', because the wine that spilled during the transit from France to England soaked into the wooden hull, making it smell sweet, or at least sweeter than it might otherwise have smelled.[14]

When Columbus set sail, the microbes he brought with him to the Americas are likely to have included European strains of brewer's yeasts. The same is likely to have been true of later colonists, including even the puritanical pilgrims on the *Mayflower*. Before Columbus arrived, there were thousands of kinds of fermentations being carried out in the Amer-

icas: fermented corn, fermented cactus, fermented cassava, fermented cacao. Those fermentations would have been carried out by different yeasts in different places. However, we do not fully know which yeasts were involved in those fermentations. This is in part because many of these fermentations have been poorly studied. But it may also be because the yeast that the colonists brought with them were so successful in their spread that they overtook the native yeasts. The story is muddy, and yet it appears as though European yeast strains spread to the Americas and around the world like cows and smallpox, like sugarcane and rum, like wheat and the conquistadors. At least that is our understanding as of today. It is certainly the case in New Zealand, where all the strains of *Saccharomyces* that are present in the country stem from colonization events from Europe.[15]

Isolation

Most of the people in the story of yeasts have become, thanks to the passage of time, anonymous, just as have most of the yeast species – most, but not all. In France, Louis Pasteur discovered germ theory not by studying pathogens (at least not initially) but instead by studying alcoholic fermentations, first beet juice and then beer and wine. Building on the work of other scientists, Pasteur provided the most unambiguous evidence that fermentation was due to living organisms in general, and to yeasts in particular. He discovered that if he sterilized grape juice that it would not ferment. Meanwhile, if he added in the organisms found in grape juice, it would. He then isolated and identified those organisms, including yeasts, which he then depicted. Pasteur's first germ theory, inspired by these yeasts, was that the germ of microbial life was required to make fermented foods. It was only later that he focused on 'germs' as the cause of disease, and even then his initial consideration was on 'diseases' of wine caused by organisms that competed with the yeasts. Ever the good caretaker of his yeasts, he focused first on sick fermentations and then only much later on sick humans.

In Copenhagen, inspired by Louis Pasteur, Emil Hansen at the Carlsberg Brewery in Denmark cultured and observed the yeast that he found in lager beer that Carlsberg was brewing (using cultures originally from the Spat brewery in Munich). He then developed technology for growing those yeasts in pure culture, on their own. As a result, Carlsberg was able to make beer that relied not just on a single yeast, but on a single strain of a single kind of lager yeast, *Saccharomyces pastorianus*. Lager yeast is a hybrid perhaps originally formed in the body of an insect, though no one knows. It is a mix of brewer's yeast and a yeast, *Saccharomyces eubayanus*, from Patagonia, and it appears to have travelled back to Europe on the colonizers'

ships. Its existence may be an artefact of both conquest and a German beer law that prevented brewers in southern Germany from brewing during the summer and so, inadvertently, favoured a cold tolerant yeast hybrid. Its isolation brought Carlsberg great wealth, but it also, as it turns out, began a process that would precipitate loss.

The strains of hybrid lager yeast cultured by Hansen spread, brewery to brewery, around the world. Something similar would come to happen with the few strains of *Saccharomyces cerevisiae*, brewer's yeast, which came to be used to make ale beers around the world, but also bread and wine and much else. Before these strains were isolated, the lager yeasts and brewer's yeasts in different places were slightly different, reflecting unique histories. The scientists at the Carlsberg brewery and elsewhere in Europe helped to obscure those differences. In doing so, they helped to favour two of the most successful eukaryotic organisms ever to live. A single brewery contains more cells of the most popular strain of brewer's yeast, for instance, than the number of humans ever to have lived. By any broad perspective, brewer's yeast and its hybrid, lager yeast, domesticated humans and led us to create a world in which it most thrives at the expense of other yeasts, and in which the foods it needs, the plant foods, thrive at the expense of other plants. The area now planted in grapes for wine is bigger than some countries. The area planted in barley for beer-making is bigger still – all to feed the yeast to make the alcohol that pleases us, sometimes at our own expense.

Visual History

This chapter is printed in a book featuring stories about loss of species, and visualizations of those species. With yeasts, there have been losses that we will shortly consider. But these losses are hidden from the visual story of yeasts.

The visual story of yeasts is largely the story of yeasts depicted in the form of the foods and drinks they create, yeasts depicted as a function of their actions. In every culture that is known to have relied heavily on yeasts, the products of yeasts are featured in art. The Egyptians depicted bread and beer, again and again. The Etruscans sculpted bowls of fermented drink onto tombs, so that the dead might sip from them. Medieval art, to the extent to which it featured any food, often included yeast-fermented wine. In the Renaissance, fermentation was everywhere. In Leonardo da Vinci's *Last Supper*, the scene is rich with gestures but also with wine glasses and leavened bread. Later, when Dutch painters began (radically) to replace religious figures and kings with still life at the centre stage of paintings,

they did so with a focus on fermented foods, and nearly always included wine or beer, and implicitly its yeasts.

Nearly every art museum in the world features the products of yeasts in one way or another. One painting, however, of which we are especially fond, sits in the Danish National Art Museum. It is a painting by the Danish artist Carl Bloch (Fig. 14.1). The painting features a busy scene in an osteria in Rome in which two women are drinking with a man. The story

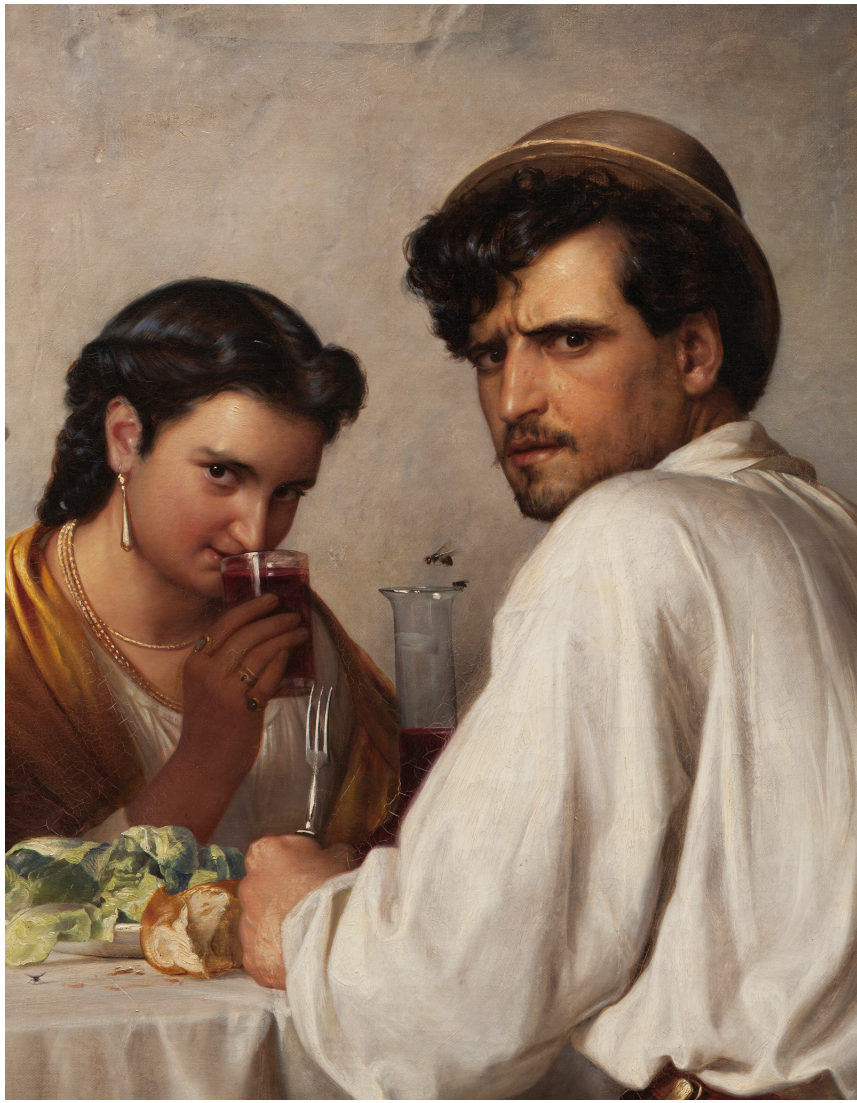

Illustration 14.1 Carl Bloch, *In a Roman Osteria* (detail), 1866. Photo by Robert Dunn.

of the painting is about the human protagonists in the scene, and also the interaction between the people and the painting and you, the viewer. But in the photo of the painting that we have shared here, we have zoomed in a little. In doing so, we reveal what is, to the painting, a subplot; and yet, as we have suggested here, a very important one. Right in the middle of the painting are glasses of wine, filled with yeasts. And hovering not far from one of those glasses is a wasp or a bee. This is one of the few pieces of art of which we are aware in which the ancient relationship between wasps, bees and yeasts, and the modern relationship between humans and yeasts, are both depicted. As for the yeasts themselves, they are hidden. Like the interaction between the man and the women or between the viewer, the man and the women, their power is implied.

What Was Lost

For as much as the products of yeast are often featured in art, the yeasts themselves rarely are. Of course, yeasts do not really care if we paint them. To the extent to which they know pleasure, theirs is simple. They enjoy being fed, cared for and ushered into the future. But because we have not depicted the yeast cells, we are relatively unable to tell which types of yeast cells might, over time, have gone missing. Meanwhile, the reason we have not depicted these yeast cells is simple – their beauty and differences are not visually conspicuous. Yeasts are visually boring. They are round. Each one is like a kind of planet, its roundness interrupted only by the umbilical scar marking the point at which, in birth, it tore away from another, identical such planet. An example here makes the point. One of us (Rob) recently asked the world expert on yeasts whether a yeast cell discovered in an ancient bread was a *Saccharomyces* cell or a yeast of some other kind. He could not tell. 'They nearly all', he said, 'look like that. Round.' The trick here is that the wondrous differences among yeasts are not with regard to their appearance; they are with regard to their consequences.

Yet, when yeasts are painted just in the form of their consequences, the foods they create, their details are hidden. In a wine glass, from a distance, no matter how well it might be painted, a rare yeast from the Amazon and the most common brewer's yeast both look the same. Their differences, even when represented in foods and drinks, are not visual. They are instead in the form of aromas and flavours.

Human noses are sophisticated. They are central to how we learn and learn to love. And yet, they are not as central to how we describe and depict the world as our eyes. Were social insects to have invented art, master-

works to grace their societies, things might have been different. Beehives might feature cells dedicated to the pleasure of aromas and the ways in which they can be mixed and set against each other to evoke responses. 'This,' they might say, 'this combination makes the queen weep. This, this triggers her awe.' But maybe we do not need to look so far, because in our own societies, are not such cells just what culinary artists have created; is not the kitchen the place in which aromas have come to be manipulated, along with tastes, to alter us, not as the viewer, but instead as the taster, as the smeller, as the one before the food. Is not a great kitchen somehow an ephemeral sort of Louvre?

The art of the kitchen features yeasts. What is more, we have words to describe the ways in which different yeasts offer us different experiences. During the same years in which Pasteur was revealing the consequences of the invisible world of microbes, the word *terroir* was brought from French into English to refer to the flavour in wine offered by the details of the land on which the grape was grown and the ways in which the wine was made. The word terroir was and is a way to capture unnameable details. Food writers have come, with time, to talk about the terroir of not only wine, but also cheese, bread and even kimchi. In the years since Pasteur, we have learned that a big contributor to terroir of a particular fermentation is the mix of microbes involved in that fermentation, including the strains of yeasts. In recent comparisons, wines made from the same grapes but different yeast strains have been shown to be more different in their flavours and aromas than wines made from different grapes but the same yeast strains. In this way, we might say that terroir is partially about yeasts and their differences, and so as we have homogenized yeasts, we have extinguished many unique types of terroir and, so too, whole galleries of culinary art, or at least the potential for such art. But there is a little more here.

Because it is hard to record culinary art, to memorialize it for posterity, we do not know what we have lost as yeasts have become homogenized. We know little with regard to which yeasts were lost as Chinese, Middle Eastern and later European cultures spread brewer's yeasts or lager yeasts in general, or the domesticated strains of those yeasts in particular, around the world. No doubt old strains of brewer's yeast and lager yeast disappeared. Some of those missing yeasts might still be found, lurking in old vessels, buried alive beneath a crumb of malt. But the bigger loss is likely to have been strains of other species and genera of yeasts, domesticated here and there around the world. It does not seem a stretch to imagine that there were ten thousand human cultures that relied on yeasts for fermentation a thousand years ago. In all likelihood, each of those ten thousand

cultures relied on a subtly (or even very) different yeast or set of yeasts for its fermentation. But they also knew how best to use those yeasts, how to favour them, how to call to them for their services. No one has gone to look for these yeasts with any earnestness. Which were the precolonial yeasts of the Americas? We do not know. Which were the precolonial yeasts of Africa? We do not know. When did brewer's yeasts arrive in the Fertile Crescent, and what was there before? We do not know. These missing microbes are implied in the ancient art of diverse cultures, implied in the depictions of the products of yeasts the way that a baker is implied in a painting of bread, a cook in a depiction of a stew, a fisherman in the fish hanging on a hook. They are implied and yet unknown, lost ingredients of our collective culinary art.

We could attempt to recreate lost yeasts by finding them in nature and culturing them, and then making new foods and drinks from them. We could look for them in the little islands of sugars out in the wild. Or we could search among the insects. Recently, Anne Madden has undertaken the latter approach. In doing so, she was able to isolate a yeast from wasps that can be used to make, on its own, sour beers, which normally require the use of a mixture of yeasts and bacteria. Recently, Anne, along with collaborators, has also found tens of yeasts in insects capable of making new kinds of breads.

Anne's work is exciting. But it depends upon the insects. Anne can only recover yeasts from insect species that still exist. Many no longer do.[16] One recent study found 70 to 80 per cent declines in insect biomass in parks in Germany. No one is sure why. Land use change? Pesticides? Climate change? Maybe all of these things. As these insects have declined in Germany and as insects have declined elsewhere around the world, have their yeasts been lost[17] via coextinction? Coextinction is the process in which one species goes extinct due to the loss of a species on which it depends.[18] What happens to a yeast if it no longer has an insect species to carry it from here to there? Some yeasts, no doubt, find new modes of transport. Others disappear.

As we lose insect species, we lose some of the yeasts that ride them. As we lose the yeasts that ride them, we lose the potential to create new kinds of culinary art, arts that have never been savoured before. If the yeasts in a particular patch of land contribute to the terroir of the wine that can be made on that land, we might also say that the insects in any land contribute to the terroir of that land; in their movements of yeasts and in providing places for yeasts to have sex, they are part of the terroir. Theirs is the entomo-terroir, the wriggling, writhing, many-legged secret to the sauce.

After

Yeasts have existed for more than a hundred million years. And while individual yeast strains and species are threatened by the ways in which we have altered the world, yeasts as a whole will live on. After humans, someday, become extinct (all species do, this is one of nature's true laws), at least some species of yeasts will still be around, taking whatever ride they can get from sweetness to sweetness. Until that time, we have some control over which yeast species we carry with us into our future. We, the three authors of this chapter, would like to think that humans will find reasons to save a rich diversity of wild yeasts and the species they depend on, with which we might make more culinary art. A paper wasp carries wild yeasts from the autumn until the spring. We need to find a way, in the context of our global society, to carry the paper wasps, and millions of other species, from this year to the next. What attracts the wasp to the yeast is the aroma of the yeast. What attracts us to the rest of life is something less concrete. It is hard to describe, and yet ancient fondness for the living world, a fondness that when sated pleases us, is a fondness on which we and many other species ultimately depend.

Acknowledgements

Special thanks to Delphine Siccard and Caiti Heil, who read and commented on this chapter.

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Notes

1. Madden et al., 'The Ecology of Insect–Yeast Relationships'.
2. Stefanini et al., 'Role of Social Wasps'.
3. Stefanini, 'Yeast–Insect Associations'.
4. Shukla et al., 'Microbiome-Assisted Carrion Preservation'.
5. Stefanini et al., 'Social Wasps Are a Saccharomyces Mating Nest'.
6. Amato, *Current Anthropology*.
7. Patrignani et al., 'Role of Surface-Inoculated *Debaryomyces Hansenii*'.
8. Lachance et al., 'Metschnikowia hamakuensis sp. nov.'.
9. Liu et al., 'Fermented Beverage and Food Storage'.
10. Katz and Voigt, 'Bread and Beer'.
11. Pontes et al., 'Revisiting the Taxonomic Synonyms'.
12. Reese et al., 'Influences of Ingredients and Bakers'.
13. Nuttall, 'Gaspar de Portolá'.
14. Philbrick, *Mayflower*.
15. Gayevskiy, Lee and Goddard, 'European Derived *Saccharomyces cerevisiae*'.
16. Dunn, 'Modern Insect Extinctions'.
17. Hallmann, 'More Than 75 Percent Decline'.
18. Dunn et al., 'The Sixth Mass Coextinction'.

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