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Review Article

Ants (Hymenoptera: Formicidae) and humans: from inspiration and metaphor to 21st-century symbiont

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Abstract

Ants have been metaphors and mirrors of the human condition for millennia. In the last fifty years, however, the potential for physical and cultural symbioses between ants and humans has been considered and, in some cases, realized. We illustrate and review ant-human symbioses in mythology, art, cinema, literature, agriculture, mining, cybernetics, artificial intelligence, and the implications of these symbioses for the push towards "becoming-with" nonhuman species. We trace a clear progression from the depiction of ant colonies as individual organisms to the recognition of them as paradigms of self-assembly and utility for solving practical engineering problems. At the same time, our social norms have evolved. The language we use to describe our own social relationships has resulted in a restructuring of the language we use to describe relationships among ants and presages further constructive symbioses between ants and people. Currently, most ant-human symbioses are one-way commensalisms (humans benefit far more than ants) in which ants are directly influencing human culture and language. Two-way mutualisms between ants and humans are hindered by their lack of a common language or the ability to translate their different languages, but two-way mutualisms may be emerging from artistic collaborations between ants and humans. However, it remains unknown whether or how ant social behavior or perception is altered by a colony's interactions with humans.

Key words: Ant control optimization, artificial intelligence, becoming-with, biological control, cleptotecton, communication, cyborg, domestication, forensics, language, mini-livestock, myrmecotektōní, myrmeculture, review, symbiosis.

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Introduction

From King Solomon, Aesop, and Plato, to Forel, Wheeler, and Wilson, people have looked to ants for inspiration, guidance, and wisdom (reviewed in Sleigh 2003). Sleigh (2007) illustrated that from the beginnings of modern myrmecology circa 1874 to the mid-1970s, perceptions of ants progressed through three metaphorical models: of the human mind, of human societies, and of human (and artificial intelligence) communication. Sleigh (2007) suggested that in this anthropomorphization of ants, there was two-way traffic between myrmecologists and their cultural milieu (i.e., culture shaped the questions myrmecologists asked and the answers directed or reinforced their cultural views). However, the utility of ants as models or metaphors for the human condition was decidedly one way: ants → humans. That is, there has been a lot of consideration by myrmecologists and sociologists of how, for example, ant societies could be models for better human ones, but much less thought of how humans could interact with ants for the betterment of both.

Our focus in this review is to examine instances in which potential cultural symbioses between ants and people have been envisioned. Biologists use the term "symbiosis" in the generic sense of two different species (usually two plants, or an animal and a plant) living in relationship with one another. That is, symbiotic associations can be mutually beneficial or not (Tab. 1; OED 2021c), but in more general use, especially in literature, the arts, and the popular imagination, symbionts are considered mutualists. Further, biological symbionts usually are in physical contact with one another. However, cultural symbioses – the creation of new dialogues between central and peripheral areas of the world that enrich cultural sensibilities while heightening concern and empathy for the "Other" (Talvet & Hix 2005), multicultural coexistence (e.g., Walker &

Tab. 1. Terms used to describe different kinds of relationships between organisms.

		Effect on species 1		
		Positive	**Neutral**	**Negative**
Effect on species 2	**Positive**	Mutualism	Commensalism	Predation or parasitism
	Neutral	Commensalism	—	Amensalism
	Negative	Predation or parasitism	Amensalism	Competition

Fig. 1: T he creation of the Myrmidons by Jove (Zeus). Image: Ortus Myrmidonum - Myrmidonen: Menschen aus Ameisen – von Zeus auf Bitten König Aiakos – aus einer Eiche herauskommend. Holzschnitt von Virgil Solis (1514 - 1562) (Myrmidons; People from ants for King Aeacus. Engraving by Virgil Solis for Ovid's Metamorphoses Book VII, 622-642.). P. Ovidii Metamorphosis VII, Frankfurt MDLXXXI (1581), fol. 94 v., imago 11. Image in the public domain <https://commons.wikimedia.org/wiki/File:Virgil_solis_ovid_metamorphosen7_11.png>, retrieved on 12 March 2021.

Fig. 2: Miniature human cavalry ride an ant in Carlton's Antasy books (Carlton 2016, 2019). Image from the defunct Illustrated Prophets of the Ghost Ants by author Clark Thomas Carlton and artist Mozchops. Image in the public domain (CC BY-SA 4.0) <https://commons.wikimedia.org/wiki/File:Prophets_of_the_Ghost_Ants_-_Anand%27s_Dream_by_m0zch0ps.jpg>, retrieved on 12 March 2021.

Winton 2017, Wu 2020), or "learning together, respecting one another, and understanding each other in a country or area where multiple cultures coexist" (Ogawa 2010: 9) – extend to all domains of human pursuits (e.g., art, architecture, literature, music, etc.) and do not require direct physical contact.

Physical and cultural symbioses between ants and humans have a long history. The earliest imagined instances we know of are in Greek and Roman mythology. Herodotus (ca. 430 BCE (Before the Common Era); translation in Herodotus 1921) recorded "gold-digging" Indian ants (Greek: Μυρμηκες Ινδικοι, Myrmêkes Indikoi) whose nest-building and tunneling activities in the deserts of the Persian Empire brought gold dust to the surface. This gold was collected by people living in the same area (Herodotus 1921: 129-133). About 400 years later, Ovid described the creation of the Myrmidons in Book VII of his Metamorphoses (ca. 8 CE (Common Era); translation and annotation in Ovid & al. 2018). Ovid's "ant-people" (their name being "true to their origin" was derived from the Greek μύρμηξ, mýrmix; Ovid & al. 2018: 173) were created by Jove (Zeus) in response to a plea by King Aeacus to restore the human population of the island of Aegina. On seeing a trail of ants carrying seeds down an oak tree (Fig. 1), Aeacus prayed to his father (Jove) to restore his people to the equal of the ants. In response, Jove transformed ants into loyal men of industry, thrift, and endurance, who followed Aeacus's exiled son Peleus to Thessaly and then fought in the Trojan War under Pele-

us's son, Achilles. Just over two millennia later, ants were re-imagined as mounts for a miniaturized human cavalry and as warriors in Clark Thomas Carlton's Antasy series (Carlton 2016, 2019; Fig. 2).

Carlton's interphyletic symbioses crystallized about 50 years of creating two-way streets between the societies of ants and humans. These pathways are underlain by mixtures of similes, metaphors, and reality in art, culture, science, and technology that have gained broad recognition and led to new thinking about tighter relationships between ants and people. In this review we move ant-human interactions from a one-way street to a multi-lane and multiway expressway by exploring how we have reframed our relationships with ants from metaphor through domestication to full-fledged partnerships. In doing so, we emphasize observations and data published in the years since Sleigh published her two influential volumes (Sleigh 2003, 2007).

Through a glass darkly – anthropomorphized ants presage human-ant symbioses

Sleigh (2003) provided a detailed historical review of similes (ants are *like* humans or vice versa) and metaphors (ants *are* humans or vice versa) about ants in broader culture. Sleigh (2007) explored further how these similes and metaphors influenced early myrmecologists and the development of myrmecology. Before we explore human-ant symbioses, we first review familiar anthropomorphic metaphors for ants and novel human cultural tropes involving ants that have emerged in the last 20 years. After this short detour, we return to the main road of domestication and emerging symbioses.

Like Haraway and others interested in interactions between humans and animals (primarily vertebrates, and "especially" domesticated animals; Haraway 2008: 5), we are wary of anthropomorphizing animal behaviors. Yet, Haraway (2008: 242) also asserted that failing to identify behaviors in terms that appear to be shared by humans and their pets (e.g., invitations, preferences, fears) is "both inaccurate and impolite" (for additional examples, see e.g., Smuts 1985, Strum 1987, Beckoff 2007). However, we follow Nagel (1974) in trying to avoid anthropomorphization of the actions and behaviors of ants. Similarly, we echo Gordon (2010b: 62) who wrote that "[r]eal ants do not offer lessons [to humans] in behavior. … There are no morals to be taken from the ants." That is, in considering symbioses from an ant's point of view and asking what it is like for an ant to be a symbiont, we are, to paraphrase Nagel (1974: 439), not asking what it would be like for us (or anyone else) to have the physical characteristics or behavioral repertoire of an ant. Rather, we are asking what it would be like for an ant to be an ant interacting with people (and conversely, what it would be like for a person to be a person interacting with ants).

Dracula ants and human vampires: Ant life histories and behaviors often are described in anthropomorphic terms that draw on imaginary and feared creatures such as vampires and zombies. Ants in several genera of the Amblyoponinae and Leptanillae bite their own larvae and consume the exuded hemolymph (Masuko 1986, Ito & Billen 1998), a feeding habit which has earned them the sobriquet "Dracula ants" (Saux & al. 2004, Ward & Fisher 2016). Unfortunately, the victims of Dracula ants receive for their pain neither eternal life nor aversions to sunlight, crucifixes, or garlic (Bunson 1993). But like vampires, Dracula ants are an ancient lineage: The Amblyoponinae is estimated to have diverged from other ant subfamilies in the mid-Cretaceous (93 - 121 Million years (Ma); Ward & Fisher 2016).

Zombie ants and the zombie apocalypse: The "zombie ants" are even more bizarre (Andersen & al. 2009, Hughes & al. 2011a). The symbiosis between *Ophiocordyceps* Petch (1931) and their host ants not only presents one of the finest examples in the animal kingdom of specialized parasite control over host behavior (Moore 2002, Hughes & al. 2012), but it also taps into deep-seated human fears of the dark side of symbioses. Spores of *Ophiocordyceps* infect individual worker ants (in the Camponotini) by penetrating their cuticle. As the fungus reproduces and spreads throughout the ant's body, it hijacks its central nervous system, causing the infected individual to climb up foliage and use its mandibles to latch onto the vegetation in a "death grip" (Pontoppidan & al. 2009). Fungal hyphae then sprout from the head of the dead ant and form a fruiting body; fungal spores from the infected corpse rain down on the forest floor, starting the cycle again. This behavior was originally described by Alfred Russel Wallace from collections he made in Sulawesi (Fawcett 1886) and is known to occur in tropical Camponotini species (in *Camponotus* Mayr, 1861*, Echinopla* Smith, F., 1857*,* and *Polyrhachis* Smith, F., 1857). In two temperate North American *Camponotus* spp., species-specific strains of *O. unilateralis* (Tul.) Petch (1931) create zombie ants that do not clutch the vegetation (de Bekker & al. 2014).

Like Dracula ants, zombie ants are an old lineage, at least 48 - 50 Ma old. The "death grip" behavioral modification caused by the fungus has been documented from fossils dating to the Eocene (48 Ma; Hughes & al. 2011b), but both the fungal lineage and those of its ant hosts are much older. Sung & al. (2008) described fruiting stalks of *Paleoophiocordyceps coccophagus* Sung, Poinar & Spatafora emerging from the head of a scale insect entombed in circa 99 - 105-Ma-old Burmese amber. Sung & al. (2008) further suggested that the crown group (Ophiocodycipitaceae) of the apparently monophyletic *Ophiocordyceps* clade also arose at least in the early Cretaceaous (109 - 138 Ma). The Camponotini lineage (the primary ant hosts) diverged at least 52 Ma ago (Moreau & Bell 2013), and two unrelated species of ants now known to be infected by *Ophiocordyceps – Pachycondyla crassinoda* (Latreille, 1802) and *Paraponera clavata* (Fabricius, 1775) (Sanjuan & al. 2015) – are in genera of comparable ages (≈ 50 Ma and 47 Ma, respectively; Moreau & Bell 2013) within a much older, albeit paraphyletic, poneroid lineage (100 - 115 Ma; Brady & al. 2006). As additional

fossils are collected and molecular clocks revised, it is possible that the evolutionary origin of ant zombification by fungi will be pushed back into the Cretaceous.

Zombies originally referred to revenant corpses animated by magic potions and spells of Haitian witch doctors and pressed into indentured servitude (Davis 1985). Perhaps ironically, zombies can be freed from their labor by feeding them salt (Connor 2021), which is now recognized as an essential element for ants as well (Kaspari & al. 2008). But contemporary zombie culture dates to George Romero's 1968 classic film *Night of the Living Dead*, in which cannibalistic zombies originated from exposure to radiation. In a tip-o'-the-hat to the air- and soil-borne fungal spores that zombify ants, the zombies in what now seems to be a never-ending stream of Z-movies and TV series are the result of infectious agents transmitted by bites, blood, or aerosols.

The dystopian fascination with zombies both metaphorical and real mirrors the current cultural zeitgeist (Boluk & Lenz 2011); their enduring appeal is reflected in the extensive press coverage of each new discovery of details of the ant-*Ophiocordyceps* system. Indeed, a search on Nexis-Uni <https://www.lexisnexis.com/en-us/professional/academic/nexis-uni.page> on 9 March 2021 returned 169 mentions of "zombie ants" in international media (2009 - 2021). Although this is not quite as many notices as the "insect apocalypse" received during the same time period (537), zombie ants, unlike the insect apocalypse, have appeared on The Simpsons (in Season 25, Episode 13; The Simpsons Wiki no date). *Ophiocordyceps* and *Cordyceps* Fr. (1818) species that turn humans into sporulating zombies also are a common trope in contemporary science fiction (Carey 2014, Vandermeer 2014, Koepp 2019), but in these stories there is not even a mention of the fungi having jumped from ant to human hosts.

But for zombie ants, perhaps a more relevant comparison than zombie movies is the 1979 science-fiction masterpiece *Alien*. The alien in this film was created from the imagination of the late Swiss artist H.R. Giger (Rinzler 2019). The hybrid morphology of the adult alien includes a dinosaur tail, eversible pharynx, sharpened teeth reminiscent of deep-sea fishes, and a segmented exoskeleton. The larval "face-hugger" stage is even more arthropod-like, with segmented appendages that resemble long human fingers or the legs of a spider crab. Indeed, the bizarre fungal fruiting body that sprouts from the head of real zombie ants could have originated from Giger's pen, and would have fit beautifully in the original film. The cultural meme that is *Alien*'s alien merged with ants in the 2019 movie *Ants on a Plane*, in which a newly evolved strain of *Paraponera clavata* (Fabricius, 1875) becomes a parasitoid of humans and creates new colonies by exploding out of the chests of feverish human hosts returning to the US on a flight from Colombia.

From slaves to cleptotectons: Beyond the imaginary vampires and zombies, anthropomorphization has figured prominently in scientific descriptions of ant social structure. So-called "slave-maker" ants, especially in the genera *Formica* Linneaus, 1758 and *Polyergus* Latreille, 1804 have been recognized for hundreds of years and inspired the writings of many 19th and 20th century authors. In *Walden*, Thoreau (1854) imagined ants as heroic soldiers in the Trojan war (perhaps recalling Ovid's Myrmidons), but he characterized the slave-makers as the "red republicans" and the hosts as the "black imperialists". This contrast may have alluded to the skin tones of American slaves and their owners but mischaracterized the hosts as an imperial power to be defeated by the people.

In *A Tramp Abroad*, Twain (1880) also mentioned raiding ants, contrasting them with "ordinary" ants, which he considered lazy: "I refer to the ordinary ant, of course; I have no experience of those wonderful Swiss and African ones which vote, keep drilled armies, hold slaves, and dispute about religion." As in numerous recent ant movies (*Antz*, *Ant-Man*, *Ant-Man and the Wasp*), both Thoreau and Twain portrayed ant soldiers and raiders as males, even though it has been known since the 1700s that all hymenopteran workers are female (Maderspacher 2007). Perhaps this will change in future cinematic portrayals of ants, in parallel with the increasing number of action movies such as *Captain Marvel* (2019) that feature female protagonists.

Metaphors are powerful tools in science (Brown 2008), and scientists find it difficult to describe any sort of animal behavior without anthropomorphizing it (Smuts 1985, Strum 1987, Zuk 1993, Beckoff 2007, Haraway 2008). However, the unique aspects of ant sexual determination, chemical communication, and social behavior, and their great phylogenetic distance from humans mean that the metaphors we use are shallow and distorted at best (Sleigh 2003, 2007). Human chattel slavery is odious, so using it as a label to describe animal behavior is troubling. Indeed, myrmecologist Joan Herbers has written commentaries in the Chronicle of Higher Education (Herbers 2006) and BioScience (Herbers 2007) in which she pointed out the cultural baggage and inaccuracy of the myrmecological terminology and suggested replacing the "slave-making ant" with the equally anthropomorphic "pirate ant".

We asked Joan Herbers to describe the events that led her to write her 2007 paper:

> "The genesis of my original article was a seminar I gave in 2005 to my department at Ohio State University. Afterwards my colleague Dr. Maria Miriti, who is Black, told me she was uneasy with the use of the term "slave-maker", but could not articulate exactly why. I pondered that awhile and had the great good fortune to know Dr. Jackie Royster, a Black rhetorician in the English department at Ohio State (who subsequently moved to Georgia Tech [that is, Georgia Institute of Technology]). Dr. Royster explained to me how rhetorical analysis shows everyday use of such terms is damaging. In particular, she directed me to an article by Toni Morrison about how literary criticism is hampered if we do not acknowledge our racialized society (Morrison 1992). I started to read more about the history of the term, and I can tell you what clinched it

for me: reading a letter that Charles Darwin wrote to J.D. Hooker on 6 May 1858 in which he writes in a P.S. "I had such a piece of luck at Moor Park: I found the rare Slave-making Ant [*Formica sanguinea* Latreille, 1798], & saw the little black [slur] [*F. fusca* Linnaeus, 1758] in their Master's nests" (Darwin 1858). That word leapt off the page for me, and I said 'enough, no more, basta'. So, I wrote the original article for the Chronicle and adapted it for BioScience."

The reactions to Herbers' two papers have been decidedly mixed. Philosophers, educators, psychologists, and rhetoricians praised them for their insights and progressive perspective (e.g., Elliott 2010, Larson 2013, Taylor & Dewsbury 2018), whereas scientists and myrmecologists pushed back (e.g., Olson & al. 2019), and offered several flawed arguments for why the label "slave-maker" should be retained (Herbers 2020). Ants have not yet weighed in on the debate.

Moreover, "slave-maker" is not the only problematic term in the myrmecological lexicon for describing the behavior and life history of social insects. Similar sociocultural issues are raised by terms such as "soldier", "caste", "virgin queen", "social parasite", and "gypsy" (Breed 2020).

Even the apparently neutral scientific term "trophallaxis" (literally food exchange; from the Greek τροφή, trofí + ἄλλαξις, allaxis) – the mouth-to-mouth or anus-to-mouth transfer of food, fluids, or pheromones between ants and by members of other social insect colonies – has been reconsidered as a loaded term distant from its utopic interpretation in the biological sciences (Jackson 2019). Exploring the implications of Simone Leigh's 2017 sculpture *Trophallaxis* – a suspended collection of black porcelain and terracotta breasts with gold and platinum nipples that are reminiscent of melons, bombs, or the distended gasters of ant repletes or fecund gynes – Jackson (2019: 1) argues that it "recalls not only racializing and imperialist histories of the breast, but also social insects as figured in political philosophy and scientific discourse. It evokes these associations by performing and inciting an investigation of a long-standing practice: the making of societal / organismic analogies, in particular the comparison of human societies with those of social insects such as ants and bees."

Reflecting once again the contemporary cultural zeitgeist, Herbers (2020) argues that it is long past the time to reconsider and rework our own myrmecological language, just as we are simultaneously restructuring the community of myrmecologists (Lucky & al. 2020). Breed's (2020) suggestion of replacing "slave-maker" with "cleptotecton" is, we think, not only an improvement on the anthropomorphic "pirate ant" but also provides an on-ramp onto the road to symbiotic relationships between humans and ants. Derived from the Ancient Greek (clepto [*κλεπτο*]: steal + tektōn [*τέκτων*]: artisan, builder, or craftsman), Breed's ants are re-conceptualized as tektōní [*τέκτωνί*]: makers and crafters. Illuminated by this 21st-century new light, the status of ants with respect to humans could be raised to that of collaborators or co-creators. We discuss this idea in more detail in two later sections of the paper, Ants and humans as co-workers, collaborators, and co-creators and Becoming-with ants.

Observing good deeds and the road to domestication

People have a long history of domesticating plants, animals, and fungi, and it is well appreciated that domestication is a co-evolutionary process that affects both humans and the organisms we have domesticated (e.g., Diamond 2002, de Freitas Lins Neto & de Albuquerque 2018, Raven 2019, Schall 2019). The co-evolutionary process that is domestication selects for genotypes and phenotypes that make the partners more useful to one another (Clement 2014). Domestication leading to physical symbioses (mutualisms) has arisen multiple times between humans and their domesticated animals or plants (see reviews in Haraway 2008, Meyer & al. 2012, Zeder 2012, Gibson 2016, Lezama-Núñez & al. 2018) and between attine ants and their farmed fungi (see reviews in Mueller & al. 2005, Branstetter & al. 2017). Although important element of domestication of animals by humans may be the former's anthropomorphization by the latter (Hecht & Horowitz 2015), interactions between humans and animals occur through a "shared arena of sensations" (Keeling 2017). Keeling (2017) even suggested that animals may domesticate humans, and that both species involved in the dance of domestication "act by way of metaphor."

Domestication may start as a one-way commensalism (humans benefit but the animals are neutral) but over time becomes a mutualism. Domestication of ants may have started with the recognition that they performed activities that were useful to people. Once such "good deeds" (a.k.a. "ecosystem services") were recognized, it may not have been such a great leap forward to deliberate domestication. Rastogi (2011) and Del Toro & al. (2012) provide thorough reviews of ant-mediated ecosystem services and disservices. Here, we highlight four of them that lend themselves to consideration as domestication of ants.

Army ants clean house: Army ants in the American tropics (species of *Eciton* Latreille, 1804) often are referred to as "visiting ants" or "(house) cleaner ants". Native peoples (and us, too, when we were living at field stations in the tropics) welcomed them into their villages, where the seemingly endless columns would pour through homes cleaning out cockroaches, fleas, rats, and assorted debris, and leaving behind a swept-clean floor (Forel 1928, Sleigh 2003). Observations and videos of these behaviors also are available widely on YouTube (a particularly good example of the genre is the 2012 short clip, *House Cleaning Ants*, <https://youtu.be/W_paIAwRqh4>, retrieved 11 March 2021). This could be considered a commensalism or a facultative mutualism since humans are, albeit perhaps inadvertently, providing food for the scavenging ants.

Ants predict changes in the seasons and the weather: People use weather forecasts and longer-term climatological predictions to time planting and harvesting

of crops. Nuptial flights and swarms of mating ants are often associated with seasonal changes in climate, such as the onset of the rainy season in the Neotropics (Attini in Brazil; Cristian Dambros, Universidade Federal de Santa Maria, pers. comm. 20 October 2020) or the shortening of the days near the autumnal equinox in the northern hemisphere (Formicinae; Forbes 1908, Tanquary 1913) – hence the common name the "Labor Day Ant" for *Lasius neoniger* Emery, 1893 (Ellison & al. 2012). The Old Farmer's Almanac, an American periodical published annually since 1818 (and now updated more frequently on the web) provides climatological predictions for the US and Canada. Hymenoptera are frequently cited in the almanac as portents of weather; notable aphorisms for ants include "[i]f anthills are high in July, the coming winter will be hard" and "[i]f ants their walls do frequently build, rain will from the clouds be spilled" (The Old Farmer's Almanac 2020). This symbiosis would best be considered a cultural commensalism.

From field and table to farm: The shift from hunting and gathering to domesticated agriculture is a major transition in the evolution of human societies (e.g., Diamond 2002, Frantz & al. 2020). Although the triggers for this transition remain debated (e.g., Diamond 2002, Barker 2009, Zeder 2015, de Freitas Lins Neto & de Albuquerque 2018), there is substantial evidence supported by genetics and theoretical models that many domesticated animals initially either were hunted and gathered or aided in hunting and gathering (Barker 2009, de Freitas Lins Neto & de Albuquerque 2018, Frantz & al. 2020).

Hymenoptera routinely emerge as one of the top three insect orders that are consumed by humans (Johnson 2010, van Huis & al. 2013), and ants have a long history of being hunted and gathered for food (i.e., predation). Some of the earliest oral records date back tens of thousands of years. For example, the Dreaming records of some of Australia's indigenous peoples (Aboriginals) attest to the importance and value of repletes of honey-pot ants (*Camponotus inflatus* Lubbock, 1880 and *Melophorus bagoti* Lubbock, 1883) (Meyer-Rochow & Changkija 1997). Written records of ant consumption in China date back to 120 BCE, and by the Tang Dynasty (618 - 907 CE), ant eggs were considered food for royalty (Luo 1997). In contemporary China, more than 30 food and health preparations containing ants or ant parts have been approved by the State Food and Drug Administration and State Health Ministry of China (van Huis & al. 2013).

Their high protein or sugar content makes ants a valuable, albeit seasonal, addition to meals, especially in tropical countries (Johnson 2010). The most common ant genera and species in human diets are *Atta* Fabricius, 1804, *Camponotus*, *Liometopum* Mayr, 1861, *Carebara vidua* Smith, F., 1858, *Camponotus inflatus*, *Melophorus bagoti*, *Oecophylla smaragdina* (Fabricius, 1775), *Pogonomyrmex barbatus* (Smith, F., 1858), and *Polyrhachis vicina* Roger, 1863 (Rastogi 2011, van Huis & al. 2013). Ant larvae are eaten raw, toasted, roasted, boiled and fried,

Fig. 3: Uncle Milton's Ant Farm™, the inspiration for modern myrmeculture. Photograph provided by and used with permission from Uncle Milton Industries, Inc. ©2013 UMI. All rights reserved. © and ™ designated trademarks of Uncle Milton Industries, Inc.

added to soups and salads as seasoning, used to produce syrup and wine, and if poor quality, fed to poultry or used as fish bait (Chen & Alue 1994, Luo 1997, Rastogi 2011). In parallel with the use described in the previous section of ants as weather forecasters, larvae of species of *Liometopum* ("escamoles") are considered ready for harvest when a common marker of seasonal phenology, *Barkleyanthus salicifolius* (Kunth) H. Rob. & Brettell, flowers in Mexico (Ramos Elorduy 1997).

However, beyond the ubiquitous toy ant farms (Fig. 3) that illustrate a cultural commensalism, ants are not yet farmed commercially. Small-scale family ant farming ("myrmeculture") has been reported from Thailand (Raloff 2008), but insects in general are difficult to domesticate in so-called "mini-livestock" systems (van Huis & al. 2013). Ants do have some characteristics that make them favorable for automated production systems: gregariousness, female-dominated altruistic groups, pheromonally-induced, promiscuous sexual behavior, short developmental cycle with high survival rates of immatures, generalist feeders on common items, and accepting of artificial diets. However, their antagonistic interactions with con- and heterospecific ants, agility, narrow or specific environmental tolerances, and antagonistic reactions to humans are traits that are less favorable for domestication (van Huis & al. 2013). Indeed, little has changed in more than 30 years of thinking about farming ants: early reviews asserted that more work was needed to develop large-scale or industrial farming of ants (DeFoliart 1997, Luo 1997, Yhoung-Aree & al. 1997); that work continues to be needed (van Huis & al. 2013). A major hurdle for farming ants is the successful reproduction of captive colonies. As with toy ant farms, it remains easier to collect mated queens from the wild and use them to produce colonies. However, this method gives the ant farmer no

control over reproduction and no way to selectively breed for desired traits.

Working in the mines: Although Herodotus's fox-size gold-digging ants clearly were mythological, there are several contemporary examples of people acting as commensals and taking advantage of the propensity of ants to move soil. As part of their nest-building activities, *Pogonomyrmex barbatus* ants in the Navajo Nation within Arizona (USA) and the nearby "Four Corners" area (the intersection of the US states of Colorado, Utah, Arizona, and New Mexico) excavate garnets (pyropes: $Mg_3Al_2(SiO_4)_3$) and deposit them on and around the anthills. These "ant garnets" or "ant hill garnets" are collected and used in jewelry (King no date). Pyrope garnets are also used as an indicator for other rocks, such as kimberlite, that can contain diamonds (Klein & Hurlbut 1999).

To the northwest of the Navajo Nation, the Red Ant Schist consists of the metasedimentary and metavolcanic rocks of Late Paleozoic / Early Mesozoic age in the northern Sierra Nevada Mountains of California and occurs discontinuously in parts of the Klamath Mountains of southwestern Oregon (Edelman & al. 1989). The Red Ant Schist includes quartzite and black mica, and occasional serpentine lenses; a later period of metamorphosis (in the Early Jurassic) in the Yuba River area of Northern California (type locality of the Red Ant Schist) is rich in garnets (Edelman & al. 1989). Although we could posit a relationship between ants, garnets and other precious gems and metals, and local geological nomenclature, Edelman & al. (1989) do not reveal why they assigned the name "Red Ant Schist" to this geological unit.

Ants also collect bones, and East African *Messor barbarus* (Linnaeus, 1767) concentrates bones of scavenged small vertebrates in its mounds. Based on observations of contemporary ant, bird, and mammal middens, Shipman & Walker (1980) hypothesized that fossil *Messor* mounds could be used to distinguish assemblages of fossils collected by different predators. Schoville & al. (2009) extended this idea to consider the taphonomic impact on archaeological artifacts of foraging, transport, and mound-building activity of *Pogonomyrmex occidentalis* (Cresson, 1865) and *Pogonomyrmex salinus* Olsen, 1934.

Ants and humans as co-workers, collaborators, and co-creators

After millennia of learning from and using ants, we still have much to discover. As we have co-evolved with the plants, fungi, and livestock that we depend on for a range of ecosystem services, so, we too are co-evolving with insects. In several realms, humans and ants already are working together in collaborative teams.

Ants as designers, fabricators, and artists: Ants have been the subject of art for centuries. In addition to Solis's 16th-century portrayal of the creation of the Myrmidons (Fig. 1), other notable myrmecological art includes Shibata Zeshin's mid-19th-century *Kaki to ari* (Persimmon and ants), which is in the collection of the Museum of Fine Arts, Boston, Salvador Dali's famous *The Persistence of Memory* (1931) in the Museum of Modern Art, New York, and M.C. Escher's *Mobius Strip II*. The first modern Aboriginal painting of the *Honey Ant Dreaming* (in 1971 by Pintupi artists, among them Kaapa Tjampitjinpa working with Billy Stockman and Long Jack Tjakamarra) is widely regarded as having launched the Western Desert Art Movement and bringing Australian Aboriginal Art to the attention of the wider ("Western") world (McLean 2011).

Fig. 4: The cover from the flier for the 2014 *Ant Farm* exhibition at the University of Southern Maine, and the page announcing the accompanying Ant Picnic to learn more about ants. Artwork by The Ant Girls; photographs of the flier © Aaron M. Ellison and used with permission.

Leaf-cutter ants (*Atta* spp.) have inspired art and been art themselves. The Ant Girls, a collaborative group of four Maine (USA) artists (Colleen Kinsella, Dorothy Schwartz, Rebecca Goodale, and Vivien Russe) initiated their 2014 project *Ant Farm: At the Nexus of Science and Art* with a reading group on ants and ant colonies. They developed prints and free-standing sculptures that were exhibited in galleries throughout Maine from 2014 - 2015, often accompanied by activities for attendees to learn more about ant identification and ecology (Fig. 4). Leaf-cutter colonies are routinely exhibited in natural history museums and are commercially cultivated for such displays (Stephenson 2021). In all these cases, ants could be seen as being in a culturally commensal relationship with humans.

Ants and people also have collaborated as cultural mutualists on artistic creations. Japanese artist Yanagi Yukinori's *The World Flag Ant Farm* (Yukinori 1990) portrays connections between peoples as series of connected world flags, each embedded within an Uncle Milton Ant Farm (Fig. 3; Uncle Milton Toys, Boca Raton, Florida) and between which the ants move and rework nationalities into an international whole. *The World Flag Ant Farm* has been exhibited at numerous locations around the world since its initial creation in 1989.

In studying the nest architecture of subterranean ants, Walter Tschinkel not only has uncovered new details of their ecology and evolutionary biology (Tschinkel 2021), but

also has created exquisite aluminum sculptures cast from the nests (Tschinkel 2010) that have been acquired by several art museums. Kuai Shen's acoustic-artistic creations also are human interpretations of ant work (Shen 2021). For these sculptures, it could be argued that the ants themselves are the sculptors, whereas each artist is the tektōn.

A different approach to collaborative explorations of ant nest casts and their temporal dynamics was explored through the textiles and crochet work of Gabrielle Duggan, Rob Dunn, Clint Penick, and Adrian Smith (Dunn & al. 2018). Penick and fabric artist Meredith West have turned patterns and textures of ant faces into pattern repeats that are used in textile design by their *Holotype* project (Penick 2021).

Ants as biological-control warriors: Myrmecological reality has outdone fiction in the path from Ovid's Myrmidons to Carlton's ant-mounted cavalry. Ants have been mobilized by humans as mutualistic agents of biological control. Although more people may have learned about this through the fictional proposal to introduce "russet ants" as biocontrol agents of forest "parasites" (Werber 1996: 56), species of red wood-ants (*Formica rufa*-group) have long been considered by scientists to have the potential to reduce populations of arthropod herbivores and predators in forests (e.g., Finnegan 1975, Cherix & Bourne 1980, Laine & Niemelä 1980, Skinner & Whittaker 1981, Fowler & MacGarvin 1985). *Formica paralugubris* Seifert, 1996 was introduced across Italy, and from there into Canada, with the goal of controlling forest herbivores (Finnegan 1975, Seifert 2016, Frizzi & al. 2018). The ants have persisted in their new locales, but their effects on the herbivorous fauna have been poorly documented (Storer & al. 2008, Seifert 2016, Frizzi & al. 2018). Unlike Carlton's ghost ants (possibly *Tapinoma melanocephalum* (Fabricius, 1793)), *F. rufa*-group ants introduced for biological control so far show limited potential for becoming "invasive" species (Seifert 2016, Frizzi & al. 2018).

Other ants considered for biological control include weaver ants (*Oecophylla smaragdina* and *Oecophylla longinoda* Latreille, 1802) that feed on herbivores of a variety of trees from which timber and non-timber forest products are derived (Chen & Alue 1994, Offenberg 2015). The earliest record of *O. smaragdina* being used as biological control in China dates back to 304 CE when it was used to control insect pests on citrus (Chen & Alue 1994). More recent work suggests that in some cases ants can control herbivores more cost-effectively than pesticides and are not a health risk for humans. Nevertheless, learning to live with aggressive weaver ants remains a challenge for farmers and foresters (Offenberg 2015). Azteca ants (*Azteca instabilis* (Smith, F., 1862)) control many pests in Neotropical coffee plantations (Vandermeer & al. 2010, Gonthier & al. 2013, Perfecto & al. 2014). Species of *Solenopsis* Westwood, 1840 control banana weevils (Mollot & al. 2012, 2014), flies that feed on passionfruit (Carrero & al. 2013), sugar-cane borers (Oliveira & al. 2012), and southern green stink bugs that feed on cotton, peanut, and soybeans (Olson & Ruberson 2012). And even harvester ants – one of the most fearsome ant races in Carlton's (2016) Antasy world – have been enlisted in the fight to control weeds in crop fields (Baraibar & al. 2009).

Ants as forensic detectives: Ants rarely kill humans, but ants, like many other insects, show up and forage at vertebrate carcasses (e.g., Early & Goff 1986, Moretti & al. 2008, 2013, Simmons & al. 2010, Eubanks & al. 2019). Ants have not figured prominently in forensic entomology (Byrd & Castner 2010, Ramón & Donoso 2015; but see Campobasso & al. 2009, Chen & al. 2014, Meyer & al. 2020). A notable example was that the presence of a colony of *Anoplolepis gracilipes* (Smith, F., 1857) in a toolbox with human remains was used to infer a PMI (post-mortem interval) of 14 - 18 months (Goff & Win 1997). But unlike insects in several well-known groups – blow flies (Calliphoridae), flesh flies (Sarcophagidae), rove beetles (Staphylinidae), and carrion beetles (Silphidae) – ants usually are not necrophagous. But when they do feed on carcasses, they can leave postmortem artefacts that may alter forensic indicators used by medical examiners (Campobasso & al. 2009, Moretti & al. 2011, Eubanks & al. 2019).

In addition, many ant species are predators that are attracted to, and feed on, other carrion-feeding insects that accumulate at carcasses and corpses. Ant predation of other necrophagous insects also can modify forensic evidence by consuming fly and beetle larvae and eggs, inflicting post-mortem damage to corpses, filling wounds with soil, or even building nests in decaying bodies (Wells & Greenberg 1994, Moretti & Ribeiro 2006, Lindgren & al. 2011, Moretti & al. 2013, Eubanks & al. 2019).

Ants and collaborating myrmecologists working as forensic entomologists supported a criminal defense case led by the late Vincent Bugliosi. Although Bugliosi was best known for his successful prosecution of Charles Manson for murder (Bugliosi & Gentry 1974), he had a long career as a defense attorney after he left the Los Angeles County (USA) District Attorney's office. In his second true-crime best-seller, *The Sea Will Tell*, Bugliosi describes how he successfully defended a young woman accused with her boyfriend of murdering an older couple and stealing their luxury boat on the remote Palmyra Island in the South Pacific in 1974. There were no witnesses, no timeline, and no bodies.

In 1981, the bones of one of the victims were discovered in a metal container that washed up on the beach at Palmyra. The bones showed signs of dismemberment and burning with an acetylene torch; in the marrow, there were insect exoskeletons "of a small, dark-colored ant approximately 4 - 5 millimeters in length" (Bugliosi & Henderson 1991: 342). For the defense of Bugliosi's client, it was critical to determine the PMI and exactly when the ants might have entered the bones. Bugliosi recalls asking in despair: "were we actually being reduced to studying ants and their habits in our efforts to learn what happened?" (Bugliosi & Henderson 1991: 343). He (Bugliosi) was quickly directed to the late Roy Snelling at

the Los Angeles County (California, USA) Museum of Natural History because "Snelling and a professor at Harvard were considered the two top ant experts in the country" (Bugliosi & Henderson 1991: 344). Snelling was able to confirm that the "grease ants" (*Solenopsis* spp.) found in the bones easily could have been attracted to oil residues in the marrow, even seven years after death. This timeframe was consistent with Bugliosi's argument that the ants had not arrived until the bones were exhumed in 1981, and that his client did not know that her boyfriend had murdered the couple in 1974. This cultural commensalism saved Bugliosi's client.

Looking ahead to the ant-people

From at least Kafka's *Metamorphosis* (Kafka 2008) to Langelaan's *The Fly* (Langelaan 1957) and its cinematic adaptations, the notion that humans could change into insects has inspired revulsion and disgust. But only four years after *The Fly* was first adapted for the screen (Clavell 1958), the ant-man debuted in *Tales to Astonish* (Lee & Lieber 1962a, 1962b). With his ability to shrink himself to the size of an ant, a supercharged costume, and cybernetic helmet that allowed him to communicate and control an army of ants, fictional biophysicist-turned-superhero crimefighter Henry Pym became the first person to integrate themselves with insect morphological and cognitive characteristics in a positive light. One year later, Pym as the ant-man became a founding member of The Avengers (Lee 1963). *Ant-Man* debuted on screen in 2015 (Wright & al. 2015), wherein the lead character is Scott Lang, a thief who steals Pym's ant suit to save his (Lang's) sick daughter. As the new ant-man, Lang left his life of crime behind, eventually joining the Avengers.

Two-way communication: Many people talk to animals, but very few (people) appear to listen (Rees 2017). Ants communicate and coordinate their behavior primarily using chemical signals (pheromones) whereas humans primarily use sound, vision, and touch. Although it was never clear how Pym's ant-man communicated with his legions of ants through his cybernetic helmet, Edmond Wells, the protagonist in Bernard Werber's novel *Les Fourmis* (translated as *Empire of the Ants*; Werber 1996) created a machine to communicate with ants that translated human words into chemical signals and vice-versa. Nonetheless, the machine was ultimately a failure and Edmond Wells lamented, "[w]e cannot even understand other human beings. How can I have presumed to understand ants!" (Werber 1996: 232). Ultimately, Wells's best hope was for either a cultural or physical commensalism: "[w]hat can ants bring us in the way of culture? Greenfly honeydew jam…their agricultural technique for growing agaric mushrooms…or boil the insects that ants collect to remove their cuticles…so that they look and taste like small shrimp" (Werber 1996: 243-244).

Cybernetic ants: The reality of cybernetic ants far eclipses its comic-book portrayal. In her discussion of ants as machines, Sleigh (2003: 153) identifies the origin of contemporary thinking of ant colonies as integrated, self-organized systems to the "rediscovery" of Wheeler's (1911) classic paper elaborating the idea of ant colonies as organisms. Indeed, Wheeler (1911: 321) wrote that "ant colonies represent a form of society very different from our own, a kind of communistic anarchy, in which there is 'neither guide, overseer, nor ruler,' as Solomon [Proverbs 6:7] correctly observed." But he left it for future researchers such as Gordon (2010a, 2016b) to answer the "formidable question" (Wheeler 1911: 320) of how cooperative behavior and colony integration was initiated or regulated. In elaborating the answers, philosophers and researchers in many fields have considered or developed semi-autonomous or fully autonomous robots or artificial intelligence (AI) systems that work for and with people on a range of theoretical and applied problems. We present here only a few examples from a rapidly expanding universe of ant-inspired or ant-controlled systems.

Ant colonies as self-assembling cybernetic systems make an early appearance in Hofstadter (1979), where he discusses the importance of holism (as opposed to reductionism) in describing the apparent coordination of an ant colony (see also the contrast between bottom-up and top-down modeling of collective behavior in Oullette & Gordon 2021). To any individual ant, Hofstadter (1979) asserted that a signal to act has no apparent purpose or plan. But the integration of these seemingly disconnected signals across the colony leads to what appears to an external (human) observer as purposeful activity (see also Gordon 2010a). Hofstadter (1979) further suggested that "Fermant's" Last Theorem, rediscovered by "Lierre de Fourmi" was solved cybernetically but never published by one "Johant Sebastiant Fermant" using an Ant Fugue with 24 voices and 24 distinct subjects, one in each of the 12 major and 12 minor keys of Western music. Ironically, however, the actual Fermat's Last Theorem was proven in 1995 using standard methods of algebraic geometry and number theory by a single human (Wiles 1995).

The use of what is now known as "ant colony optimization" (ACO) or "ant colony systems" (ACS) – algorithms first developed by Marco Dorigo in his dissertation (Dorigo 1992, Dorigo & Gambardella 1997; Dorigo & al. 2006 is an accessible review) – has far outstripped its early applications to telecommunications, hardware design, and table-top robots reviewed by Sleigh (2003). ACO was perhaps the first "reactive" (as opposed to "conventional" or "classical") algorithm applied to navigation by robots and other AI systems (reviewed in Patle & al. 2019, Valdez 2020). ACO can be applied to more navigational methods than any other algorithm because of its high capacity to explore effectively the local and global environment, efficient computation, rapid responses and actions, flexibility, and autonomous "decision-making" ability (Tan & al. 2007, Patle & al. 2019).

Dorigo (1992) developed his initial, 2-dimensional ACO from observations of pheromone-based foraging behavior (Dorigo & al. 2006). Within five years of its publication, a simpler ACS was incorporated into NetLogo, a widely used programming and modeling environment for

simulating multi-agent dynamics (Wilensky 1999). The NetLogo Ants model (Wilensky 1997) has been broadly integrated into teaching computer science in secondary schools, colleges, and universities (Borowczak & Burrows 2019), which may partly explain the broad popularity of ACOs and their integration into AI systems (another example of a cultural symbiosis evolving into a meme). As ACOs have been extended from their original 2-dimensional formulations into 3-dimensions (Wang & al. 2019, Pu & al. 2020) and with better parameterizations (Valdez 2020), they have been used in diverse lab and field applications such as detection of epistatic interactions in genome-wide association studies (Shang & al. 2019), water resource management (Afshar & al. 2015), route planning for unmanned vehicles (Zhang & Zhang 2019), autonomous robot navigation (Dupeyroux & al. 2019), missile guidance (Gao & al. 2013), image processing (Liu & al. 2014), and surveillance (Tinoco & al. 2019).

Ants are incorporated into an artificial intelligence in Tchaikovsky's (2018, 2019) pair of science-fiction novels. In Children of Time (Tchaikovsky 2018), a human scientist, Avrana Kern, is sent into space by an unnamed government on an ecocidal and soon-to-be-uninhabitable Earth to find and terraform other planets for future human colonists. Kern has developed a "virus" with gene drive (like a super genetically modified *Wolbachia* Hertig, 1936) to accelerate evolution on the planets she finds. Her hopes are dashed when her mission is scuttled by a group of anti-science zealots who escaped Earth before its environmental Armageddon, tracked her down, and destroyed her ship, but not before she released the virus onto the planet below and put herself into cryogenic suspension in an orbiting escape pod. Resident species of ants, spiders, and stomatopods were infected and evolved different degrees of sentience. Eventually, the spiders domesticated the ants and used them to solve complex problems (as suggested in Hofstadter's 1979 Ant Fugue and Gordon 2016a). When Kern is finally revived, only her mind is still (somewhat) intact. Her memories, together with an ant colony capable of parallel computation, were fused into the ship's computer system where they worked as a complete mutualistic symbiont (Tchaikovsky 2019).

Ants as designers and builders: The well-known ability of fire ants (*Solenopsis invicta* Buren, 1972) to self-assemble into three-dimensional structures such as rafts and towers (Mlot & al. 2011, 2012, Phonekeo & al. 2017) has led to the development of an optimization routine with engineering applications (Nave & al. 2020). Although no robot (or robot swarm) yet exists with the capacity to sense their neighbors, climb on and off one another, and support construction loads, once such robots are built, Nave & al. (2020) have produced an application that could be used with them to design and build towers with specified shapes and dynamic properties including mechanical stability and modest mobility. Szuba (2017) proposed such a system based on a similar algorithm: a bridge or scaffolding system self-assembled by robots working together like ants building rafts. Szuba's (2017) bridge system is intended to be delivered to areas affected by earthquakes or similar disasters to help with debris removal and search-and-rescue operations.

Becoming-with ants

When viewing ants as collaborators and physical or cultural symbionts, we are assuming some degree of "agency" on the part of the ants. Rees (2017) described agency in a partnership between two or more individuals (here, ants and people) as occurring when they share the volition and intent to proceed in a particular direction. Critically, she noted that such partnerships "raise potential ambivalences between animal intent, training and instinct" (Rees 2017: 3). In considering the examples of Yukinori's, Tschinkel's, and Shen's artistic collaborations with ants, for which we considered the ants to be the artists and the human artists to be the tektōni, one reviewer of this paper asked "what does it mean from the ant's perspective to participate in these [artistic] endeavors? ... Is it reasonable for us to view them as the artist, even though we know their own perspective would not include this?" Following Nagel (1974), however, unless we are ants, we cannot know whether the ants' perspective would include us (although they indeed might; see Swoboda 2019). This applies equally well to the question of how what we now call cleptotectonic ants would describe themselves and their actions.

A key challenge in achieving any true partnership with ants is for people to "become-with" (sensu Haraway 2008) ants. The path to understanding the differences between domestication, collaboration, and a symbiotic "become-with" begins with Derrida, who asserted that "[o]ne never eats entirely on one's own" (Derrida 1991: 115). Jumping off from the observations that heterotrophs eat other organisms and microbes are part of the digestive process, Haraway first joined the concepts of companionship (from the Latin *cum panis* ["with bread"]; OED 2021a) and respect (*respicere* ["to look again"]; OED 2021b). She then observed that the root of *respicere* is *specĕre*. Although *specĕre* originally meant "to look or behold", it also is the root of "species". But she does not consider "species" to be the Platonic ideal of the systematist but rather a "mental impression or idea; [for which] thinking and seeing are clones" (Haraway 2008: 17). Finally, the knotting together of companion and species (into what we have suggested would be a collaboration, partnership, or symbiosis) in a respectful encounter is "to enter the world of becoming-with, where *who and what are* is precisely what is at stake" (Haraway 2008: 19; *italics* in the original). Perhaps more concisely, "human nature is an interspecies relationship" (Tsing 2012: 141).

It is important to recognize that "becoming-with" is not domestication. Rather, domestication is a part of an "anthropo-zoo-genetic practice" (Despret 2004: 122) that "constructs both animals and humans in historically situated interrelationships ... [for whom] articulating bodies to each other is always a political question about collective lives" (Haraway 2008: 207). Domestication also adds

new identities; partners learn to be affected; they become available to events; and they engage in relationships that disclose perplexity (see also Despret 2005, Despret & Meuret 2012). But there is neither *cum panis* nor *respecere* in the relationship between the domesticator and the domesticated. Philosophers, sociologists, critical thinkers, and others consider "animals" — in the context of domesticated animals and "becoming-with" associations with animals – to be only mammals (REES 2017). We are only beginning to imagine what it might mean to fully "become-with" an ant, much less plants or any other invertebrate (but see Ellison 2019, in press).

Recalling the story of future therolinguists (linguists of the *θηρο* [wild beast]) trying to decipher the language of ants (LeGuin 1974), Haraway saw ant-*Acacia* mutualisms (e.g., Ward 2017) as a quintessential example of how becoming-with involves "reaching into the internal tissues of each participant, shaping genomes and developmental patterning of the structures and functions of both companion species" (Haraway 2016: 124). In the wide range of ant-*Acacia* mutualisms, symbiogenesis is not only a synonym for the good (Tab. 1), but also an instance of "becoming-with each other in response-ability" (Haraway 2016: 125).

From envisioning ants as cybernetic computational devices (e.g., Hofstadter 1979) to their incorporation as and into artificial intelligences (e.g., Chakraborty & Kar 2017, Tchaikovsky 2018, 2019), ant-human symbioses reveal the "leaky distinction between animal-human (organism) and machine" (Haraway 2006: 120). Both cyborgs and symbioses reveal the affective relationships between humans and others that are crucial to "becomings", and insist that we reframe the simple categories in which we humans frame interspecific interactions (e.g., Tab. 1; see also Latimer 2016). This is a profoundly democratic move, far removed from the longstanding metaphor of ant colonies as hierarchical superorganisms controlled by a single queen (compare Wheeler 1911 with, e.g., Gordon 2016b). Indeed, one of the protagonists in Swoboda's audio drama *The ants* (*after Caryl Churchill*) asserts: "I would rather be a part of a cyborg than of this superorganism" (Swoboda 2019: at time 5:10).

Concluding remarks

The jump from ants as similes or metaphors for the human condition to ant-human collaborations, symbioses, and cyborgs has occurred remarkably fast relative to the millennia of interactions between ants and humans (Sleigh 2003, 2007). It took less than a century to go from the identification of an ant colony as analogous to a single organism (Wheeler 1911) through the domestication of ants to models of ant colony self-assembly (Dorigo 1992) and their use in solving significant and practical engineering problems (Patle & al. 2019, Valdez 2020). As our social mores and norms have evolved in tandem with the emergence of ant-human collaborations, the language we use to describe our own social relationships has led us to rethink and reframe the language we use to describe the relationships among ants (Herbers 2006, 2007, 2020, Breed 2020). Whether this reframing leads to a time when we "become-with" ants remains to be seen. But based on progress made in the last 20 years, we should at least look forward to a future of further constructive symbioses with the myrmecotektōní.

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