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Periodical Cicadas and the Abundance of Time

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▼ **ABSTRACT** The life cycle of periodical cicadas, like the scientists who have studied them, is characterized by periods of long waiting punctuated with spectacular bouts of activity. In remarkable synchrony, every thirteen or seventeen years—depending on the species and the location—billions of nymphs crawl from the ground and embark on a relatively short adult life span of three to four weeks. This paper traces three pulses in the scientific study of periodical cicadas, as researchers sought to determine the geographical range of the broods, the number and biological identity of the species found in each brood, and the relationship between the individual and the swarm. Together these threads of research highlight the historical significance of mass collaboration in the scientific study of these charismatic animals and the surprisingly entangled affective relations between human and insect.

▼ **KEYWORDS** periodical cicadas; Richard D. Alexander; evolution; temporality; John Cooley; insect song; citizen science

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In the early summer of 2021, John Cooley drove along back country roads of the northeastern United States at thirty-five miles per hour with his windows rolled down. His radio was turned off. He was listening for the sound of periodical cicadas calling from the nearby trees. On his dashboard was a Raspberry Pi, loaded with geopositional data from the cicadas' previous emergence in 2004. As he drove, he correlated past and present, looking to see how their distribution had changed in the intervening seventeen years. His goal was to help create a set of maps that accurately depicted the distribution of each brood of periodical cicadas in North America, spatial snapshots that together conveyed where each brood can be found in space and time.[1]

The history of scientific efforts to understand periodical cicadas is deeply tied to the sounds they produce.[2] Cicadas find mates by following their singing, sorting into distinct species according to auditory cues.[3] In classical tradition, when the Muses were created, some humans had sung with such committed passion that without food or water, they died. From them sprung cicadas, granted by the Muses a capacity to sing from birth to death without sustenance.[4] People from many cultures have kept individual cicadas to listen to them sing, just as they have with crickets.[5]

In 2021, the three species of *Magicicada* that comprise Brood X put in a cacophonous showing in the mid-Atlantic region of the United States. Without the ongoing global COVID-19 pandemic, I might have been traveling. Instead, I spent weeks as an amateur naturalist, observing and recording my impressions of the cicadas as they popped up in my yard, screamed from the campus treetops, sucked sap from the delicate branches of new growth in deciduous trees (classical literature notwithstanding, they do eat), and then, their energy spent, decayed in the summer heat. I was not the only local obsessed with the bugs; on the path outside the university's day care center, I spotted a vibrant six-foot, five-color chalk drawing of a cicada. Like any good naturalist, I documented the specimen and made note of its location. I had experienced this same brood thirty-four years earlier. (I missed the intervening 2004 emergence, however, as I was in the upper Midwest conducting research for my dissertation on the history of female choice in evolutionary biology.[6]) My interest in the history of evolutionary theory—especially female choice—had been sparked by the three years I spent in graduate school at the University of

1 e.g., Cooley et al., "Documenting Single-Generation Range," and Simon et al., "Advances in the Evolution." On maps and time, see Rankin, "Mapping Time."

2 Kritsky, *Periodical Cicadas*.

3 Riley, "Song Notes."

4 Shapin, "Philosopher and the Chicken."

5 Raffles, *Insectopedia*.

6 Milam, *Looking*.

Figure 1. The above ground stages of cicada development. *Frontispiece*, drawn by Charles Valentine Riley for Marlatt, *The Periodical Cicada* (1898). Source: National Agricultural Library Digital Collections, U.S. Department of Agriculture.

Michigan in a department where questions of sexual selection and the possible connections between animal and human behavior were highly politicized.[7]

It was at Michigan that I met Cooley and his long-time collaborator David Marshall, who were then fellow graduate students. They were working with zoologist Richard Alexander on the behavior and evolution of periodical cicadas.[8] So when I had questions about cicadas two decades later, I reached out to them. Cooley had likewise been obsessed with cicadas as a young boy, although he was not then familiar with the periodical species. Growing up in the Midwest, *Neotibicen pruinosus* had provided the soundtrack of his summers. For his senior thesis at Yale, Cooley had hoped to write about insect genetics and showed up in the department with a "giant bag of frozen

7 For example, compare Alexander, *Darwinism and Human Affairs*; Low, *Why Sex Matters*; and Vandermeer, *Reconstructing Biology*.
8 Cooley, "Sexual Behavior"; Marshall, "Behavior and Evolution."

cicadas," but that had not panned out.[9] By the time he reached graduate school, Cooley was working on the reproduction of high-alpine syrphids and blister beetles—he wanted to understand how and why they sorted into leks, or mating arenas.[10] Once he started his field research, however, Cooley ended up switching species, as these kinds of questions were far easier to answer with cicadas. It felt like he had come full circle.[11]

This paper traces the relationship between individuals and groups, with particular attention paid to time as experientially entangled for the cicadas and the scientists who study them.[12] In dialogue with the sudden raucous appearance and equally abrupt disappearance of Brood X in the eastern half of North America in 2021, it charts the intellectual history of scientific attempts to understand the life cycles of periodical cicadas and theories of their evolution [**Fig. 1**]. Each section addresses a separate pulse of inquiry, if you will, that preoccupied periodical cicada researchers during the last century: Where were they located? How many species of periodical cicada were there, and how did they tell each other apart? What was the relationship between the individual and swarm in life cycles of periodical cicadas? Together these threads of research highlight the historical significance of mass collaboration in the scientific study of these charismatic animals and the surprisingly entangled affective relations between human and insect.[13] In this context, the puzzle of the temporality of cicadas concerns how discontinuous time can be shared and rendered social, across species and scientists.[14]

Brood Emergence

Natural historians have known about seventeen-year periodical cicadas for centuries. The first account of periodical cicadas in the scientific literature constituted a brief report in 1666 describing the "swarms of strange insects" in New England that "broke forth in the form of Maggots, which turned into Flyes that had a kind of taile or sting, which they struck into the Trees and thereby envenomed and killed it."[15] Following this brief mention in the *Philosophical Transactions*, these North American insects also appeared in the

9 Milam, interview with Cooley.
10 Cooley, "Functional Hypotheses."
11 Milam, interview with Cooley.
12 On temporality and biological systems, see e.g., Gould, *Time's Arrow, Time's Cycle*, and Hopwood et al. "Cycles and Circulation."
13 See also Hui, "Listening to Extinction."
14 On organic parts and wholes, see Lidgard and Nyhart, *Biological Individuality*; on discontinuous time and cryptobiosis, see Roosth, "Life, Not Itself." On suspended animation, see Radin, *Life on Ice*, and Radin and Kowal, eds., *Cryopolitics*.
15 Oldenburg, "Observations of Swarms."

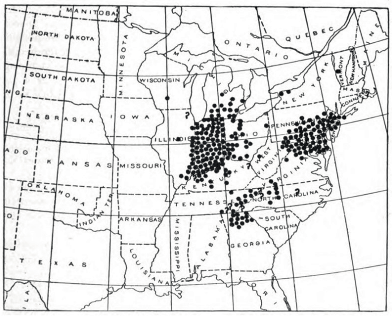

Fig. 8.—Map showing distribution of Brood XXII, 1902.

Figure 2A.

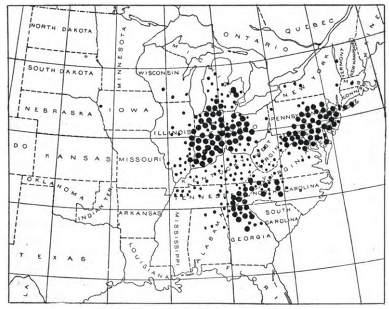

Fig. 13.—Map showing distribution of Brood X, 1919.

Figure 2B.

Figures 2A–2B. Marlatt's projected distribution of periodical cicadas, published in anticipation of the 1902 emergence of Brood XXII (**left**), by U.S. Department of Agriculture (Marlatt, *The Periodical Cicada*, 1898). **Right**: Renamed Brood X, Marlatt's revised map predicting their 1919 emergence (Marlatt, *The Periodical Cicada*, 1907).

tenth edition of Linneaus' *Systema Naturae* in 1758, described as a single, endemic species: *Cicada septendecim*.[16]

Only in the late nineteenth century did entomologists start separating them into distinct broods based on the timing of their emergence and mapping their geographic distribution in North America. Mapping distributions required coordination between naturalists based in different states [**Fig. 2A** and **Fig. 2B**], as undertaken by Charles Valentine Riley in his position as U.S. Entomologist for the Department of Agriculture.[17] Riley died unexpectedly in 1895—the result of a tragic bicycling accident—and his successor entomologist Charles Marlatt continued the process of systematizing the emergence of periodical cicada broods by year and bringing to order other naturalists' naming conventions.[18] In 1898, the brood he referred to as XXII was the largest of the seventeen-year broods, called Brood No. 4 by one expert and XVI by another. In 1885, its appearance was confused by the co-emergence of a thirteen-year brood and his map predicted the likely emergence of the cicadas again in 1902. By 1907, he called this same cohort Brood X and updated his maps based on data gathered five years earlier (which in turn served as predictions for 1919). Marlatt used evidence from the past to plot future likely emergences, recording spatial distributions in temporal flux.

Popular accounts of periodical cicada emergence focus on the apparent dormancy of cicadas, which is a trait they share with their ancestors and other

16 On ideas of insect metamorphosis before Linneaus, see Ogilvie, "Order of Insects."

17 On ties between entomology, agriculture, and nationalism during this time, see Pauly, *Fruits and Plains*. For Riley's requests for confirmation of emergence records, see Riley, "Periodical Cicada" (1893), Riley "Periodical Cicada in Massachusetts."

18 Marlatt, *The Periodical Cicada*.

non-periodical cicadas living today. We might imagine cicadas' experiences underground as akin to how Jacob von Uexküll described ticks waiting for a warm-blooded mammal to pass underneath them—without any social interactions and seemingly without sensory input, he described them as largely insensible to the passage of time.[19] Charles Riley had been fascinated by the significant portion of cicadas' lives spent underground, beyond the limits of human observation. When his experiments raising them in confinement failed, he resorted to digging outdoors at regular intervals in places where he knew they could be found.[20] By Riley's account, the larvae were not dormant and continued to move and develop slowly during these years, each individual living alone in a mobile earthen cell of its own creation. They also appeared to be moulting continuously. Riley reasoned that this morphological clue indicated the cicadas were using their claws for burrowing the entire time they lived underground: otherwise, why molt so often? In the year of their ascent, he noted that pupae could be found just underneath the surface, easily seen by overturning logs and stones, having moved in the previous year nearer and nearer the interface with the air, so as to emerge in concert at "the opportune moment."[21]

In the 1920s, entomologist W.T. Davis named the genus of the periodical cicada *Magicicada*, reputedly out of awe for this remarkable synchronicity.[22] According to research conducted decades later, these insects count by tracking seasonal changes in the tree sap they consume.[23] Indeed, many insects count.[24] Plants, too. In 1970, Stephen Jay Gould pondered the capacity of a bamboo species (*Phyllostachys bambusoides*) to unerringly flower and set seed every 120 years.[25] He noted that, rather like cicadas, the plants were far from inactive in the intervening years, producing new shoots and propagating asexually, and then, having produced a massive quantity of seeds, they died. The ability of organisms like insects and bamboo to count is remarkable, but what remains especially strange in these cases is their synchronization—within cicada broods (and bamboo species) almost all individuals are physiologically coordinated to reproduce at the same moment across vast geographic regions.

The brevity of cicadas' time above ground necessitates the synchronization of scientists' observations across the distribution of each brood. This makes the long-term study of cicadas different from other projects that track the behavior of animal populations continuously over decades.[26] Given the slowness with which cicadas move underground, their capacity to migrate to new ecological

19 Uexküll, "Stroll Through the Worlds."
20 Riley, "Periodical Cicada" (1885).
21 Riley, "Periodical Cicada" (1885), 520.
22 Davis, "*Cicada tibicen*."
23 Karban, Black, and Weinbaum, "How 17-year Cicadas."
24 Hayes, "Bugs that Count."
25 Gould, "Bamboo Clock."
26 Milam, "Landscapes of Time."

spaces depends on their mothers' distribution while air-borne: where they land and mate, where they lay their eggs, and where the larvae of the new generation re-emerge. Cicadas cannot survive the years living in the soil without access to deciduous tree roots, so their distribution is limited by the central plains to the west and the evergreen forests to the north [**Fig. 2A** and **Fig. 2B**].[27]

Charting how cicadas moved in ecological space required mapping how geographic distributions of periodical cicadas have shifted over generations—a long-term enterprise (after all, each population could be observed only once every thirteen or seventeen years) concentrated in short bursts of time.[28] The more fine-scale the desired resolution, the greater the number of individual observers whose efforts needed to be coordinated. Tracing these geographic shifts required what we now call crowd-sourced or citizen science, but the roots of the practice were essential to the creation of modern scientific expertise—the contributions of amateurs' individual observations added to the scientific authority of those who calculated and made sense of the amalgamated results.[29]

Choruses within Synchronies

Cicadas move through space and time in coordinated but irregular patterns: slow and solitary below ground, fast and loud above. Since the late-nineteenth-century scientists have mapped the ecological movement of individuals by tracing the mobile edges of their collective distributions. By the mid-twentieth century, biologists were increasingly fascinated by a new conundrum—that these coordinated broods are in fact composed of multiple species. This raised a series of new questions about how these insects could tell each other apart.

Richard Alexander studied the vocalizations of insects for his dissertation research in entomology at Ohio State University in the 1950s [**Fig. 3**]. When he died in 2018 at the age of eighty-eight, his students and collaborators hailed him as "an iconic American success story." He was born on a small farm in Illinois with no electricity or indoor plumbing.[30] He started his PhD after serving in the army during the Korean War, and applied military technology to the study of insect sounds.[31] Insect calls, in Alexander's early analyses, were

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27 White, Lloyd, and Karban, "Why Don't Periodical Cicadas."

28 Rare astronomical events follow similar patterns: Woolf, *The Transits of Venus*; Pang, *Empire and the Sun*; Kennefick, *No Shadow*.

29 Shuttleworth, "Life in the Zooniverse"; Daston and Lunbeck, *Histories of Scientific Observation*; Reidy, *Tides of History*; Coen, *Earthquake Observers*.

30 Summers et al., "Obituary." See also Alexander, "Understanding Ourselves."

31 Alexander, "Capturing the Melodies"; Alexander, "Comparative Study," 42–63. He adapted the technique from his advisor Don Borror, who started recording the sounds of birds on OSU's main campus in the late 1940s: Borror, "Analysis of Repeated Records." On the history of ornithology and bioacoustics, see Hui, "Listening to Extinction."

The author demonstrating the use of an aluminum parabolic reflector with the Magnemite Portable 610-E to record cicadas and other treetop singing insects.

Figure 3. Richard Alexander conducting research for his dissertation (Alexander, "Capturing the Melodies", 35). He noted in the article that insect sounds are among the oldest animal sounds on Earth. Their songs could sound monotonous to human ears but can be complex when played back at reduced speeds. Source: National Agricultural Library Digital Collections, U.S. Department of Agriculture.

crucial for understanding communication and the role of sound in maintaining species cohesion or, alternatively, speciation.

When Alexander started his research, entomologists disagreed about how many species of periodical cicadas existed. Together with entomologist Thomas E. Moore, Alexander identified six separate species, all belonging to a single genus, *Magicicada*. This species complex consisted of three sets of related pairs, split into thirteen- and seventeen-year sibling species. The southern part of the periodical cicadas' range was dominated by thirteen-year species and the northern range by species with seventeen-year life cycles. This meant that biologically distinct species emerged in synergistic years—what kept them apart, according to Alexander, were their mating calls.[32]

32 Alexander and Moore, "Studies on the Acoustical," and "Evolutionary Relationships."

After earning his PhD, Alexander spent his career at the University of Michigan, and by the mid-1970s had fundamentally re-oriented his thinking about animal behavior, evolutionary theory, and inevitably insect song.[33] He became particularly impressed with the work of George C. Williams, W.D. Hamilton, and John Maynard Smith on evolution and animal behavior.[34] When the director of the natural history museum at Michigan, where his appointment was based, found a little extra money and decided to allocate it to a series of visiting distinguished professors, Alexander talked him into inviting each of these men in turn.[35] A few years later Hamilton wrote inquiring about the possibility of a permanent position in the United States, and quickly joined the faculty at Michigan. By then a doyen of quantitative approaches to kinship relations and social behavior, Hamilton brought the full force of the new evolutionary theory to his conversations with Alexander at Michigan.[36] By the end of Alexander's career, this meant writing about the evolution of social behavior in horses.[37] In the shorter term, however, he embraced individual selection as the mechanism through which to reason evolutionarily, including about insects.

Unsurprisingly, most accounts of the emergence of periodical cicadas have depicted them as a swarm, a mass of undifferentiated individuals notable for their sheer abundance and collective noise.[38] For Henry David Thoreau, the sound of cicadas epitomized summer in the deep woods of the mid-Atlantic states. In an essay on the "Natural History of Massachusetts" (1842), he asked his readers to remember "the shrill roll-call of the harvest fly" that had played, too, in the ears of the ancient Greeks. He translated an ode attributed to Anacreon, pronouncing the cicada the "sweet prophet of summer."[39] By flexing their tymbal organs, males produce a series of rapid clicks that resonate in their hollow abdominal cavities.[40] The hotter the afternoon, the louder they call.

Perhaps the most famous recounting of the emergence of a periodical cicada brood dates to 1970, when Bob Dylan released "Day of the Locusts" memorializing the June summer morning when he had traveled to Princeton University to receive an honorary Doctorate of Music.[41] Cicadas sang in the distance and Dylan wrote that he was glad to leave them behind and get out of

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33 Alexander, "Evolution of Social Behavior"; Alexander, "Understanding Ourselves."

34 Hamilton, "Genetical Theory"; Williams, *Adaptation and Natural Selection*, and *Sex and Evolution*; Maynard Smith, "Group Selection," and *Mathematical Ideas*.

35 Alexander, *Notes on the Faculty*.

36 Segerstråle, *Nature's Oracle*; Alexander, "William B. Hamilton Remembered." Worth noting, too, is that Alexander had a rather volatile relationship with E.O. Wilson, as evidenced from their extensive correspondence that show both frustration and mutual respect in equal measure. Edward O. Wilson Papers, 1931–2015, MSS78062, Manuscript Division, Library of Congress, Washington DC.

37 Alexander, *Teaching Yourself*.

38 Raffles, *Insectopedia*.

39 Thoreau, "Natural History of Massachusetts," 6.

40 Nahirney et al., "What the Buzz."

41 Anon., "Bob Dylan Receives Honorary."

town alive.[42] The song leaves ambiguous whether it was the insects, the heat, or the company that drove his relief at escaping to the Dakota hills.

Three life cycles after Dylan's New Jersey misadventure, I trained myself to recognize calls from the three different species of *Magicicada* that constitute Brood X. It helped that males of the same species tend to cluster together, so that each tree acquired its own distinct sound.[43] Females find a mate by parsing the deafening cacophony into that of the right species and, as she gets closer, into individual calls. One sounded like intermittent mini-chainsaws, *zzzzzzzzz* (*M. septendecula*); the second like an old-fashioned lawn sprinkler, *click-click-click-buzzzzzzzz* (*M. cassini*); the third possessed an unmistakable falling whoop at the end of the call, *wheeee-ooo* (*M. septendecim*). Riley had referred to this final call as the "*phar-r-r-r-aoh* note," and the connotation had reinforced contemporary associations of cicadas with locusts.[44]

Fears of insect pests, the capacity of swarms to consume vast fields, and the ability to reproduce uncountable numbers of themselves, have guided agricultural practices for ages.[45] By the last years of the nineteenth century and the early decades of the twentieth, ecologists concerned about invasive species in the United States paid particular attention to unwanted insect voyagers that transgressed national boundaries.[46] In these discussions, insects required technical and diplomatic intervention, mirroring changing contemporary understandings of race, migration, and bionativism, where the insects were always alien, always dangerous.[47] With the widespread adoption of chemical pesticides by mid-century, American farmers and households alike declared a war on insects that merged fears of invading hordes with the technological optimism of chemical solutions.[48] Of the many species that populate the earth, insects are perhaps the most difficult to incorporate into an imagined happy and healthy relationship with humans.[49]

Alexander approached the implied conundrum of the relationship of an insect individual to the collective swarm with which it is associated through neo-Darwinian evolutionary theories. In the midst of the public controversy following E.O. Wilson's publication of *Sociobiology* in 1975, Alexander warned about throwing the baby out with the bathwater.[50] In with all the "erroneous, careless, ignorant or asinine remarks by determinists or anti-determinists" (the so-called bathwater), was a baby or "the real relationship of organic evolution

42 Dylan, "Day of the Locusts."
43 Sheppard, "Self-Organizing Cicada Choruses."
44 Riley, "Song Notes," 264.
45 Pauly, "Fighting the Hessian Fly"; one might even think back to the eighth plague of *Exodus*.
46 Subramaniam, *Ghost Stories for Darwin*; Pauly, "Beauty and Menace."
47 Subramaniam, "Aliens Have Landed!"; Pauly, "Fighting the Hessian Fly"; Shinozuka, *Biotic Borders*.
48 Russell, *War and Nature*; Tsutsui, "Looking Straight at *THEM!*"
49 Social insects are an important exception to this generalization, e.g., Coen, "Experimental Multispecies Household"; Lustig, "Ants and the Nature"; Munz, *The Dancing Bees*.
50 Wilson, *Sociobiology*. On the controversy, see Segerstråle, *Defenders of the Truth*, and *Nature's Oracle*.

to human social behavior—the real relationship between genes and culture."[51] He cautioned scientists against ignoring the powerful tool that evolutionary reasoning provided for understanding the natural world, including humans.

Alexander spelled out the implications of this new theoretical framework for the study of insect song. "Only a few years ago," he wrote, "most biologists referred to insect choruses as mating assemblies and supposed that a sufficient explanation had thereby been provided"—indeed, he had written about insect singing in just this way.[52] Alexander recalled the rare occasions when he noticed that all the individuals in a specific area had synchronized the rhythm of their individual calls. He described one such moment from a sunny day in early June 1957: "… the males of one of the two seventeen-year cicada species I was studying suddenly (within a few seconds) entered into a massive synchrony extending several hundred meters, from one end of the forest to the other."[53] He had noticed this spectacular coordination again in the blinking pattern of fireflies in Kentucky, and then in katydids in the Appalachian Mountains. He thought this kind of chorusing behavior required a biological explanation based in the advantages that could accrue to individuals, not solely to the group. Choruses like these were thought to constitute a kind of super stimulus, attracting to the area both females and other males of the same species, but neither of these advantages seemed sufficient to explain the group's behavior. Instead, Alexander pointed to the social nature of calling: in the presence of other individuals, males changed their signaling pattern, sometimes to synchronize with them or to alternate calls.[54] In this context, he posited, one could understand such mating aggregations as occasions of intense competition for mates—a spontaneous moment in time and space when males coordinated to gain increased access to nearby females.[55]

In cicadas this insight seemed especially relevant, as each Brood contained a mix of up to three species sharing the same periodical cycle. Over the course of thirty years, Alexander's research questions had shifted from a quest to understand insect acoustics to, in the context of sociobiology, the hope of uncovering the role of insect song in the intraspecific competition for mates and the processes of speciation in sympatric species—both topics of investigation required understanding the geography of cicada species distributions.

Charismatic Insects

In May 2021, as I contemplated the incipient arrival of Brood X in New Jersey, I read an advertisement from a local pesticide company. It assured me

51 Alexander, "Evolution, Human Behavior," 20.
52 Alexander, "Natural Selection," 36; e.g., Alexander, "Social Communication"; Alexander, *Singing Insects*.
53 Alexander, "Natural Selection," 39.
54 Alexander, "Natural Selection," 38–42.
55 Alexander, "Natural Selection," 71.

that nothing could be done about the coming emergence. Periodical cicadas, it insisted, exhibited an "evolutionary super strategy." The best option was to wait six weeks and their above ground life cycle would be complete. Biologists today are less fascinated by cicadas' capacity to remain underground for years at a time—non-periodical species do that, too—than why the life cycles of individuals became synchronized. Two possibilities co-exist: that synchronization served to satiate predators (this was the "super strategy" to which the pesticide company referred) and that it helped the cicadas survive cool summers in the unpredictable climatic conditions at the edge of glaciation thousands of years ago. The "predator satiation" strategy is more common in plants, where masting or mast seeding allows most bamboo seeds or acorns, for example, to be eaten as long as a few grow into the bamboo stalks and oak trees of the next generation.[56] Both hypotheses are premised on the evolutionary conceit that long-term survival requires enormous loss of individual life to hungry predators or the changing environmental conditions.[57] (For Cooley, neither explanation is fully satisfactory: all species of cicadas have predators and non-periodical cicadas in North America have also weathered changes in glaciation.[58])

Despite the anticipated public horror of the promised emergence, cicadas are among the most charismatic fauna of the phylum Arthropoda and offer a fascinating glimpse into the kinds of affective relationships people invest in insects that are large enough to take on personalities, transforming them into oracles of society and the ecological future of humanity. In this mode, the moral of cicada narratives, both scientific and artistic, calls for self-reflection rather than a description of the other.

At first sight, periodical cicadas do not appear to be well-designed. They live grave-deep for years and spend a few spare weeks as adults, driven to mate before dying. They are awkward in flight, slow to react, and are happy to cling to any vertical surface: people, fences, traffic signs. Plus, a defining aspect of their short adult lives is that everything loves to eat them: squirrels, geese, blue jays, robins, groundhogs, deer, and of course dogs. They are high in protein, low in fat, and are easy to locate. Riley, ever their promoter, told a journalist in 1885 not to be afraid of eating them. "They are only the quintessence of vegetable juices," he said, "and everything in nature feeds upon them ravenously."[59] Over a century later, a 2004 cookbook included such recipes as cicada dumplings, cicada stir-fry, cicada-rhubarb pie, and more.[60] The cookbook explained that prospective consumers should gather the tenerals, newly hatched, before their shells had a chance to harden. The authors suggested harvesting them in the early morning, just after emergence.

56 Pesendorfer et al., "Ecology and Evolution."
57 Sterelny and Griffiths, *Sex and Death*.
58 Milam, interview with Cooley.
59 Anonymous, "A New Breakfast Dish," 1.
60 Jadin, *Cicada-licious*.

As cicadas share the muscle protein tropomyosin with shrimp, crabs, and lobsters, medical authorities are unanimous that people with shellfish allergies avoid eating cicadas. One of the local ice-cream shops even offered a cicada ice-cream, which I could not bring myself to try.

In recent decades the work of empathy in incorporating animals into human kinship relations has fallen most often to the arts and humanities, into art and song.[61] In the case of cicadas, that affective bond has been forged through sound rather than sight. Margaret Atwood wrote a sexy poem about cicadas (not the periodical kind) that linked the desire to mate with a sense that death was near.[62] The conceit of her lovely, brief poem was to treat its subject as an individual rather than a swarm, one driven by the pressure of time to sing insistently. In a second poem about cicadas, Clint Smith imagined a conversation between an African American teenager and a cicada, who passed along hard-earned advice—the cicada's song turned to angelic warning.[63] The kinship evinced in the connection between individual animal and human echoes with strength in numbers, loss of kin, and rebirth.[64] In Smith's poem, the individual life and the swarm intersect. Personal memories of affective connections to individuals bind us through a creative process of care and reciprocity.

In contrast, in evolutionary analyses of behavior scientists like Alexander have sought to understand humans as animals—that is to say, zoomorphically—using tools developed for analyzing the sociality of non-human species as a guide for interpreting the biological imperatives that shape humans' instinctive behavioral responses. Resistance to sociobiological reasoning solidified in the mid-1970s along exactly these lines, echoing long-standing tropes about the naturalistic fallacy, and calling attention to the role of science in perpetuating social stereotypes about gender and race.[65]

In those same decades, scientists also imported techniques from the study of human social relations, both psychological and anthropological, to research projects that focused on non-human animal behavior. Especially in long-term studies of animal behavior, researchers incorporated focal observations of single individuals in a community, documenting changing social relations over the course of their lives.[66] Research on periodical cicadas has been in many ways the opposite of these long-term projects. Their sheer numbers and life cycle preclude tracing genealogies and kinship relations. The brevity of their

61 e.g., Tsing, *Mushroom*; Heise, *Imagining Extinction*; Jørgensen, *Recovering Lost Species*.

62 Atwood, "Cicada." You can listen to Atwood read her poem on *All Things Considered*, Kelly, "Margaret Atwood."

63 Smith, "What the Cicada Said." You can listen to him read the poem on *Ours Poetica*, Smith, "Clint Smith."

64 Benjamin, "Black AfterLives Matter."

65 Longino, *Studying Human Behavior*; Daston, *Against Nature*; Milam, *Creatures of Cain*.

66 e.g., Goodall, *Shadow of Man*; Moss, *Elephant Memories*. They are, in essence, dynamic archives of behavior: Aronova et al., "Historicizing Big Data"; Daston, *Science in the Archives*, Milam, "Landscapes of Time."

lives above ground requires massive collaborations to chart their wide distribution. (There is also no chance that the insect subjects would react to their observers as social entities.[67]) The mass, synchronized emergence of periodical cicadas poses the difficulty of knowing something that happens rarely and quickly. Each brood emergence enrolls scientists in a logistical scramble of mass listening, recording, and analyzing.

A Collective Abundance of Time

According to Cooley, each observer's set of eyes creates a pixel in a digital photograph that together capture a snapshot in time of a species' distribution.[68] But where have researchers found these pixel generators? Riley used his publications in *Science* as advertisements to get other entomologists to send him observations from the geographical region in which they worked.[69] By the second half of the twentieth century, cicada researchers telephoned other scientists to ask about cicada emergence in their region. The growing popularity of the World Wide Web changed this pattern; rather than scientists reaching out, curious amateurs could now find scientists with expertise. In the mid-1990s, in the early years of Netscape Navigator, Cooley and Marshall had created a webpage with answers to a few basic questions about cicadas. Working with Alexander meant that they would otherwise have spent all spring answering the phone rather than conducting their own research. The webpage quickly grew, as they added digitized sound recordings and scans of pinned specimens to help people identify the different species, and answers to the questions people were calling to ask. Those early files are still present on the most recent incarnation of the website.[70] This worked until the 2004 emergence of Brood X. They had posted a request on their webpage for people to email them records of cicada emergence in their area, preferably verified with a photograph. That summer they received close to 50,000 emails, far more than they expected or could handle.

Looking ahead to the emergence of Brood XIII in Chicago three years later, cicada researchers worked with the *Chicago Tribune* to build an interactive map where readers could upload records to a collective site. At the end of the summer, the *Tribune* handed over the back-end coding, the "keys to the car" as Cooley put it.[71] They had to comb through the 4,885 'crowdsourced records' submitted by the general public, but it worked well—only 100 or so had to be discarded because they were uploaded at times when the cicadas were not present, were geo-located in bodies of water, or fell outside the

67 Smuts, "Encounters with Animal Minds."
68 Milam, interview with Cooley.
69 Riley, "Periodical Cicada" (1893), and "Periodical Cicada in Massachusetts."
70 Team Cicada, General Periodical Cicada Information.
71 Biemer, "Cicada Brood."

continental United States.[72] So they turned the infrastructure into a web app where users could type in the location of their sightings of other broods. With time and each updated operating system, of course, it became laborious and more difficult to maintain.

The next, and most recent, solution came from entomologist Gene Kritsky, who together with the Center for IT Engagement at Mount St. Joseph University built the app Cicada Safari for smartphones.[73] Kritsky and his students sifted through over 100,000 photographs a year, culling the real records of cicadas from everything else that people might playfully upload.[74] Human eyes checked every photograph. Given the percentage of discards, it became hard for scientists to put a lot of weight on these anonymous data, but the records served as antennae for previously unknown populations. If something weird but plausible popped up—in other words, a record from Bristol, Tennessee, rather than a clearly spurious sighting in Antarctica—they checked out the report. In the summer of 2012, for example, that Bristol record turned out to be a previously unreported disjunct population of periodical cicadas. University of Connecticut librarian Carolyn Mills checked old newspapers, providing evidence that this was indeed a long-standing full emergence well-known to locals, just not to cicada scientists. Crowd-sourced data have been crucial for identifying false absences in known distributions.

If this historian's gaze has been on the past, perhaps the periodical cicadas can help us contemplate the future, wrenching my vision from their discarded shells to anticipate their re-emergence. For periodical cicadas that future is characterized by habitat destruction, a common fate in the Anthropocene. Given the years they spend living underground, cicadas' survival is susceptible to industrial development, neighborhood improvement projects, and anything that causes the death of the trees on whose roots they are feeding or pours concrete over the places where they could emerge.[75] They also tend to survive better in some soils than others. The broods that live in the sandy regions of Long Island have fast been disappearing and scientists were worried they had gone extinct—reports from the summer of 2021 bore news of a single, small emergence, Brood X's last foothold in the state of New York.[76] Cicadas, I hope, can help us think proactively about the world into which they take wing.

The current biogeographical distributions of periodical cicadas are transcripts of insect and human collective histories: scientists cannot ask big evolutionary questions without knowing *where* the cicadas are located and *how* they

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72 Cooley et al., "A GIS-Based Map." See also Cooley et al., "Distribution of Periodical Cicadas," on the 1997 emergence of Brood III.

73 Kritsky, *Cicada Safari*.

74 According to Cooley, directions that include "send us a photograph" tend to generate all kinds of unsavory false results; Milam, interview with Cooley.

75 Young, "Some Facts and Theories."

76 Giaimo, "Disappearing Cicadas."

communicate, and that requires a mass coordination of human observers.[77] There is still much we do not understand about periodical cicadas, including the ecological effects of the aeration of the soil created when they burrow through the ground from the tree roots, the impact of the arrival of this massive food source in the above-ground ecosystem, and the way that cicadas both concentrate and redistribute nutrients in their environments. Their fate and that of the scientists who study them are wound together with duct tape, staples, and a lot of gasoline. This science requires less grant money than you might think—merely a collective abundance of time.

About the Author

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77 Simon et al., "Advances in the Evolution."

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