Outracing All Your Devoted Enemies?

The Periodic Cicada (and its bizarre fungal pathogen)

Tovi Lehmann – Silver Spring, Maryland

At the midst of the excitement and almost at the end of the countdown, we heard that they will not sing in our town. "Just wait seven years," a neighbor said. We missed them by a month when we moved to Maryland in 2004, finding only dead bodies and hearing the stories. Amazing is an understatement in describing the periodic cicadas, the longest-lived insects. Mama cicada lays 20 eggs in each nest she scratches on tree branches, maybe 500 eggs in total. After a few weeks new larvae hatch, say "see you in seventeen years," drop to the ground, and dig down to find a nice root to suck on. Imagine spending 99.5% of your life in a narrow dark dungeon, checking again and again a mysterious clock only to find out that your first play-date is sixteen years away. Neighbors in the tunnels around you, members of the annual (dog-day) cicada species leave after one, two, or three years, but for the periodic cicadas, time stands still. Waiting to see the light and weighing the prospects of a beak-to-beak meeting with a hungry bird, what is their meaning of life (and is it worth it)? I cannot address this question today, but recently we paid a visit to these stoic, albeit noisy, creatures in Fairfax County, Virginia, only 20 miles away, where a good gathering had already started. Did they skip our neighborhood for vanity alone? What would be better than taking a flight to test their new wings? On the other hand, there are many things to do once they are released from their underground tunnel.

Soon after their soft, new clothing (cuticle) hardens, the fresh adults enter a frenzy of courting (male song) and mating, as choices are many. With densities reaching nearly 1 billion/acre during the 3-4 weeks-long breeding season, predators gorge themselves with periodic cicadas but can only reach a small fraction of them, a phenomenon called "predator satiation." These unbelievable numbers increase the chances of survival and reproduction of the average cicada, despite the lack of typical defense mechanisms, such as chemical toxins, deterrents, camouflage, or a fast-escape response.

Most biologists believe that no predator is so patient as to wait 17 or even 13 years for the next cicada emergence and those few that are patient, forget what they are waiting for or cannot track the years during the long interval between adult-emergence events. In other words, the periodic cicadas rid themselves of predators by living protected underground for incredibly long periods and their synchronous, yet short, adult activity above ground –when they are exposed to only opportunistic predators. Emerging

Figure 1. Adult *Magicicada* on the lookout.

Figure 2. Chimney openings (holes) in the ground are early signs of the emergence of adult cicadas (left). The nymphs molt into adults, leaving their old skin behind (right).

at long intervals of a prime number of years further decreases even a predator's ability to guess their appearance. This strategy has been adopted by three 17-year cicada species and four 13-year species, each with several "broods" that are confined to particular locations.

Unlike the annual cicadas that face specialized predators such as the Cicada Killer (*Sphecious speciosus*), among other wasps, and the Mississippi Kite (raptor), periodic cicadas emerge before their annual kin and are believed to have no specialized predator. However, they are attacked by a fungal pathogen *Massospora cicadina*. Even during our short walk in the park of Fairfax County, we found several infected cicadas dead and a few that moved about although parts of their abdomens were missing, showing instead a stub coated with a mat of fungal spores. What a gruesome way to die. Apparently *M. cicadina* attacks only periodic cicadas and "ignores" annual cicadas (which are not susceptible). Infection occurs when the nymphs crawl through their chimneys near the surface, where they spend the last few weeks before reaching the surface once the soil temperature reaches 65°F. Days after infection, the cicada's abdomen will be converted into a factory of asexual fungal spores (conidia) rendering the insect sterile. Instead of cicada offspring, mating attempts will lead to new fungal infections in their would-be lovers. Moreover, spores filling the abdomen are shed after the last segments of the abdomen simply fall apart, exposing a white-gray mass of spores. Angie Macias wrote a great blog on that fungus, describing its mode of transmission as "Flying Salt Shakers of Death," despite claiming that poetry is not her thing (Angie's, not the fungus's). *Massospora* exploits the mating system of the cicadas as genitally-mutilated male and female cicadas (after the fungus has caused the progressive dropping of the posterior abdominal segments) continue interacting with other cicadas in their large mating aggregations in the treetops, and thus, spreading the fungus among many hopeful life-partners. The second round of infection in cicadas that acquire the fungus as adults (after emergence from the nymphal skin), leads to the production of sexual thick-walled spores that presumably stay dormant in the soil for 17 years. Again the spores are spread as abdominal segments are lost while the cicada moves and flies around quite like a flying salt shaker (see facing page). A single cicada produces one type of spore; not both. The resting spores visible on the abdomen have a darker yellow-brown color. Since experiments in spore germination in the laboratory have failed, it is believed that the resting spores require 13 or 17 years to germinate (presumably the longest expected life cycle of any fungus); a little too long for the average graduate student to complete his or her thesis. Duke and colleagues (2002) found that the resting spores are not necessarily synchronous with their hosts but can germinate and infect periodic cicadas upon contact with a susceptible cicada nymph while in their chimney, regardless of whether it is a 13- or 17-year cicada. In her blog, Angie Macias speculated about the evolution of this fungus, whose genus *Massospora* has a taste for cicada flesh across the world. So *M. cicadina* is the only known specialized control agent of periodic cicadas. Indeed, high densities of periodic cicadas were correlated with low rate of infection with *M. cicadina*. The ability to produce lasting, dormant spores is a talent few predators possess, yet many microorganisms do. The sheer quantity of spore production necessary to withstand the dilution in the ground over the years is uniquely a fungal advantage. After all, very few other spore-producing organisms match fungi in the quantity of spores they shed. *Massospora* accomplishes two "spore amplification" cycles during the rather short 3-4 weeks of adult cicada activity and produces two different spores with totally different germination programs. The resting spores are ready to infect periodic cicadas at their first intimate

Figure 3. Adult *Magicicada* in an intimate embrace in the middle of the road.

Figure 4. The sad end of the infected cicadas (their rear) showing broken abdomens that were dedicated to production of fungal spores.

contact, as spores can germinate and invade through the cuticle rather than after being ingested.

With a biomass of over 200 tons/acre, periodic cicadas represent an appealing nutritional resource for predators, yet they successfully minimize predation pressure by slowing down their development at the cost of extending their generation time. Against all expert advice, advocating shorter generation time, these creatures have shaken virtually all predators, parasitoids, and almost all pathogens by doing their thing – slowly. Only *Massospora* is known to "anticipate" the emergence of periodic cicadas, and act as a specialized population control agent. That a fungus would crack this hard and sophisticated defense of a group of very guarded and prudent insects, while adapting to their incredible life cycle and sexual habits, is a testimony to the amazing adaptive capacity of fungi. It may also be a testimony that there is no safe route in life, regardless of the price one pays to buy it.

Further Reading

http://www.cicadamania.com/where.html

Macias, A. 2013. Flying salt shakers of death. http://blog.mycology.cornell.edu/2013/02/19/flying-salt-shakers-of-death/

Duke, L., D.C. Steinkraus, J.E. English, and K.G. Smith 2002. Infectivity of resting spores of *Massospora cicadina* (Entomophthorales: Entomophthoraceae), an entomopathogenic fungus of periodic cicadas (*Magicicada* spp.) (Homoptera: Cicadidae). *Journal of Invertebrate Pathology* 80(1):1-6.