The IPM Practitioner
Monitoring the Field of Pest Management
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Special Pheromone Report

Bats, Pesticides and White Nose Syndrome

By William Quarles


Courtesy Alan Hicks, New York State Dept. Environ. Conserv.

A little brown bat, *Myotis lucifugus*, shows signs of white nose syndrome. Wings, nose, and ears have been attacked by the white fungus, *Geomyces destructans.*

Millions of hibernating bats in the U.S. have been killed by a mysterious new disease. Death is associated with a fungus, *Geomyces destructans*, that attacks their skin. White fungal lesions appear on their bodies and on their noses, which has led to the name "white nose syndrome." *G. destructans* has attacked at least nine different bat species, and according to biologists at the U.S. Fish and Wildlife Service, more than 5.5 million bats in 20 states have died since 2006 (FWS 2012; USGS 2013).

Bats are an indicator species, interacting with many elements of the ecosystem. Mass die-off of bats is not good news, as it could signal deeper troubles. Bats have low reproductive rates, usually one offspring per year. Once a population undergoes mass mortality, recovery is expected to be slow, if at all (Jones et al. 2009; Blehert 2012).

The first cases were found near Albany, New York in 2006, and most of the deaths so far have been confined to the Northeast. But the fungus has been detected in the Midwest and in the South, and it "may be spreading along summer and winter migration routes of bats" (Ren et al. 2012). Spread of the disease through the corn belt and other vast agricultural areas could lead to widespread loss of crop protection provided by bats (Boyles et al. 2011). The problem may emerge sooner rather than later. Diseased bats have recently been found in Iowa and in Illinois (USGS 2013).

The corn belt already has its problems. Pests are becoming resistant to the insect protection provided by genetically altered crops. As a result, we have seen increased use of systemic chemical pesticides such as neonicotinoids. Glyphosate resistant crops have led to increased herbicide use. This combination has brought a series of environmental problems such as increased bee mortality, and loss of wildlife habitat (Quarles 2011ab; Hopwood et al. 2012; Pleasants and Oberhauser 2012).

Biological controls are part of the IPM solution for pesticide resistance. Loss of bat biological control could lead to increased pesticide applications and further environmental degradation (Boyles et al. 2011).

Caused by Fungus

White nose syndrome is a disease caused by a fungus. Lethal fungus diseases in mammals are unusual, and they are often due to compromised immune systems. The fungus

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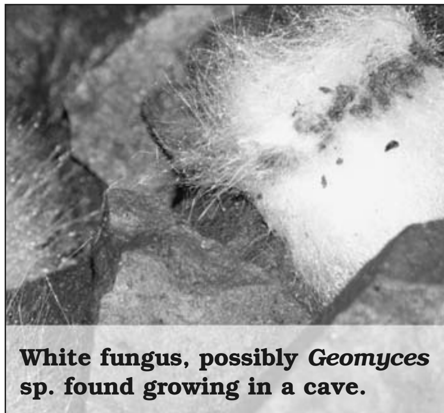
is transmitted by contact between bats. When laboratory colonies of bats were inoculated with *G. destructans*, they developed the lesions found in naturally infected colonies. Infected bats woke often from hibernation, lost weight, and started dying within 88 days of



White fungus, possibly *Geomyces* sp. found growing in a cave.

Courtesy USGS National Wildlife Health Center

inoculation (Lorch et al. 2011; Warnecke et al. 2012).

The fungus is able to live outside its host. The pathogen has been detected in U.S. soil samples, and viable spores have been found in bat caves. The fungus prefers low temperatures (3-15°C;37-59°F, >90% humidity). Maximum growth rate is at 14°C (57°F), and it is probably not a threat to humans (Hallam and Federico 2012; Hayes 2012). It can be dispersed by "air, water, bird feathers, animal hair, arthropods, and humans and their equipment" (Hayes 2012).

White nose fungus has many elements in common with the fungus *Batrachochytrium dendrobatidis*, which has caused massive die-offs in amphibian populations (Eskew and Todd 2013). Pesticide contamination has been proposed as a contributing factor in both diseases (Shah 2010).

A fungus is also killing frogs.

Photo courtesy of Gary Nafis

Hibernating Bats

More than half of U.S. bat species hibernate (Foley et al. 2011). Bats most affected by the fungus are species such as the little brown bat, *Myotis lucifugus*, that hibernate in very large numbers in cool caves (hibernacula). Populations in infected hibernacula have been declining by about 73% each year. Projected decline of the little brown bat is from 6.5 million to 65,000 in less than 20 years (Frick et al. 2010). Mortality is more likely when the weather outside the cave is dry and cold (Flory et al. 2012).

Other bats infected so far include gray bats, *M. grisescens*; endangered Indiana bats, *M. sodalis*; northern long-eared bat, *M. septentrionalis*; eastern small footed bat, *M. leibii*; southeastern bat, *M. austroriparius*; cave bat, *M. velifer*; tricolored bat, *Perimyotis subflavus*; and big brown bat, *Eptesicus fuscus*. It is not known whether or not the fungus will spread to species that do not hibernate (Frick et al. 2010; Foley et al. 2011).

Where Did it Come From?

Either the fungus was already here, or it has been recently introduced. *Geomyces* spp. have been discovered throughout the U.S., and avirulent strains may have preceeded the outbreak. But the strain of *G. destructans* causing disease shows little genetic variation between geographic sites, which implies recent introduction (Eskew and Todd 2013).

G. destructans is widespread in Europe, and the U.S. pathogen may have originated there. Inoculation of U.S. bats with the European fungus gave mortality rates similar to inoculation with the U.S. version of *G. destructans* (Warnecke et al. 2012; Foley et al. 2011).

Immune System Involvement?

Whether it is native or introduced, the immune system of U.S. bats cannot deal with it. *G. destructans* is found in Europe, but mass mortality of bats has not been seen there. European bats may have evolved resistance to the pathogen, and probably have immune system protection. The immune system of U.S. bats is unable to prevent infection and death, either because acquired immunity to the novel pathogen is slow to develop, or because the immune systems of U.S. bats are generally compromised. Hibernation itself causes depressed immune function, and any additional environmental insult could be the tipping point (Eskew and Todd 2013; Warnecke et al. 2012).

Bats hibernate in groups, and the fungus is spread by intimate contact. Infected bats wake often, depleting food stored for hibernation.

Courtesy Nancy Heaslip, New York State Dept. Environ. Conserv.

Fat Bats Favored?

A number of things could lead to immune suppression. Improper nutrition could have an effect. Bats are voracious foragers, eating close to their weight in insects every day. If their food supply is reduced, due either to pesticides or weather conditions, improper nutrition might lead to a depressed immune system (Barclay and Dolan 1991; Kannan et al. 2010; Burles et al. 2008).

Diseased bats are often emaciated, but no one has established a recent nutritional baseline in areas where populations are crashing. Kunz et al. (1998) found average weight of about 9.1 g and average fat reserves of about 2.5 g, or 27%, in healthy adult little brown bats at prehibernation swarming sites in Vermont. Minimum fat reserves for survival in normal circumstances should be about 1.5 g (Hallam and Federico 2012). Storm and Boyles (2011) found average weights during hibernation of 7.6 g in healthy adult little brown bats from Ohio and 6.3 g in sick bats from New York.

A little brown bat has white nose syndrome. Infected bats often starve to death.

Courtesy Alan Hicks, NYS DEC

Hibernating bats must live for up to six months on stored fat. Diseased bats wake often during hibernation. Each time they wake up, about 5% of their energy reserves are utilized (Warnecke et al. 2012).

Dying bats often show signs of starvation. Wing lesions from the fungus also cause a water loss. Diseased bats are often seen flying outside in daylight, presumably looking for food and water. It is likely that fatter bats have a better chance of survival (Storm and Boyles 2011).

On the other hand, fat deposits might help them survive, but may not prevent infection. Laboratory colonies of male Canadian little brown bats inoculated with the fungus had an average weight of 8.6 g, but contracted the disease anyway (Warnecke et al. 2012).

Bats and Pesticides

Bat immune systems may be depressed from environmental contamination or pesticide residues. Little brown bats can live for 34 years, and often eat their body weight of insects every day (Brunet-Rossini and Wilkinson 2009). With this kind of metabolic flow, they are vulnerable to accumulation of pesticides and environmental contaminants, especially persistent ones. For instance, turf treated with chlordane 30 years ago led to contaminated beetles that recently killed foraging bats (Stansley et al. 2001).

The association between bats and pesticide toxicity was studied frequently during the time DDT, chlordane, dieldrin and other organochlorine pesticides were in widespread use. Deaths from DDT, dieldrin, and chlordane were fairly common. These pesticides also had multigenerational transmission to immature bats through mother's milk (O'Shea and Johnston 2009; Rattner 2009).

Extermination with DDT

DDT was sometimes actually used to deliberately exterminate bat colonies. Studies of poisoned bats showed periodic waves of toxicity as

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DDT was mobilized from fat. As fat reserves dropped, toxicity increased (Kunz et al. 1977; Clark 1988).

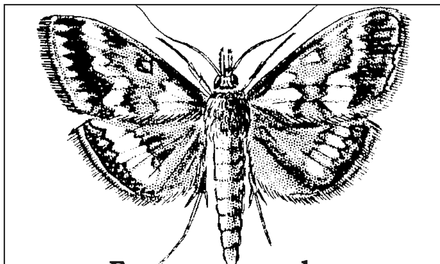
We might expect a pesticide problem where agricultural or turf insects are the bat food supply and resistant pests live long enough for bats to eat them. DDT is persistent and has led to bat population declines at Carlsbad Cavern, New Mexico (Clark 2001). Organophosphates have been associated with deaths of the endangered Indiana bat, *Myotis sodalis* (Eidels et al. 2007). Sprays of chlorpyrifos-methyl and fenoxycarb in European apple orchards led to reproductive risk in bats that gleaned insects from treated foliage (Stahlschmidt and Bruhl 2012).

Most of the bat pesticide studies have involved acute toxicity, and pesticides studied have been mostly organophosphates or organochlorines. Very little has been published on the effects of pyrethroids, but esfenvalerate and permethrin have been found in carcasses of little brown bats. And apparently nothing has been published on either acute or sublethal effects of neonicotinoids, fipronil and other modern pesticides on bats (O'Shea and Johnston 2009).

Pesticides and White Nose Syndrome

As mentioned earlier, little brown bats can live for 34 years. Long lifetimes can lead to a large accumulation of persistent pesticides (Brunet-Rossini and Wilkinson 2009). Kannan et al. (2010) compared diseased bats from New York (average weight 6.1 g) with healthy bats from Kentucky (average weight 6.8 g). Bats were collected in the wild near the end of hibernation.

Concentrations of DDT and PCBs in sick bats were 1/10 to 1/1000 of the lethal dose. Average DDT lipid concentrations in sick bats (12100 ng/g) were about six times those found in healthy bats (2460 ng/g). DDT concentrations in diseased bats were ten to one hundred times higher than healthy bats found in Spain or India. Concentrations of PCBs in sick bat tissues exceeded the toxic threshold for marine mammals (Kannan et al. 2010).



European corn borer, *Ostrinia nubilalis*

High exposures of this kind can lead to immunosuppression and enhancement of metabolic rate in bats. Immunosuppression would make them more susceptible to white nose fungus, and higher metabolic rates would deplete fats faster, leading to the emaciation seen in dying bats (Kannan et al. 2010; O'Shea and Johnston 2009).

White nose syndrome may also be influenced by an outlier effect. Though average DDT lipid concentrations in sick bats was 12,100 ng/g, one bat had 26,900 ng/g (Kannan et al. 2010). The most contaminated and weakest bats may get the disease first. The weakest may then spread it by contact to other bats.

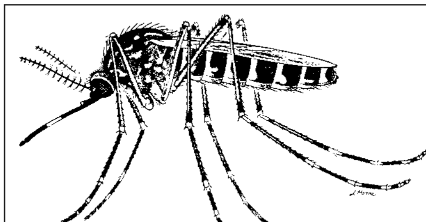
Food Supply of Bats

Insects are the major food item for bats. Bats either catch flying insects in a technique called hawking, or they glean stationary insects from foliage and other locations. Hunting strategy varies, and some bat species use both gleaning and hawking (Ratcliffe and Dawson 2003). They use sonar and a sharp sense of hearing to locate insect prey. Some insects can hear the swooping bats and try to avoid them. Arctiid moths emit ultrasonic clicks to confuse attacking bats. Bat predation often becomes a sonic war, with moths countering bat sonar with sonic activity of their own (Clare et al 2009).

DNA analysis has greatly increased knowledge of bat diet. Kinds of insects consumed vary with the bat species. For instance, the little brown bat efficiently harvests swarms of aquatic insects. Nearly a third of its diet in some locations is the mayfly *Caenis* sp. So the little brown bat's nutrition may rely on water quality. Water pollution would lead to less food (Belwood and Fenton 1976; Clare et al. 2011).

If there is a pesticide connection between aquatic insects and the problems of the little brown bat, it might be due to mosquito insecticides. West Nile virus has often caused aggressive applications of mosquito adulticides as a defensive measure. Methoprene and BTI also have an impact on populations of chironomids (gnats) that are food for the little brown bat (Belwood and Fenton 1976; Niemi et al. 1999; Quarles 2001). Reduced aquatic insects would drive the bat to seek alternate food such as moths, but it might be less successful (Long 1996).

Other bats, such as the eastern red bat, *Lasiurus borealis*, eat mostly Lepidoptera. A DNA analysis showed major prey for this bat came from Geometridae, Pyrilidae, and Noctuidae families. More than 60% of the prey were species that could detect bats, but were caught anyway. Pests included the gypsy moth, *Lymantria dispar*; the black cutworm, *Agrotis ipsilon*; codling moth, *Cydia* sp.; and tent caterpillars, *Malacosoma* sp. (Clare et al. 2009). The endangered Indiana bat, *M. sodalis*, also feeds mainly on moths (Lee and McCracken 2004).



West Nile mosquito, *Culex tarsalis*

Feeding is to some degree opportunistic. For instance, the number of Brazilian free tailed bats, *Tadarida brasiliensis*, eating corn earworm moths, *Helicoverpa zea*, is associated with moth abundance. Bats track pest populations and forage where moths are most

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Pink bollworm, *P. gossypiella*, is eaten by bats.

Courtesy Peggy Greb, USDA

numerous (McCracken et al. 2012). Corn earworm would probably be most abundant in areas where it is resistant to pesticides. Resistant moths might be carrying significant concentrations of residual pesticides. Since so little has been published, it may take some time to test the connection between pesticides and white nose syndrome.

Loss of Bats Lead to Increased Pesticides

A single colony of 150 big brown bats, *Eptesicus fuscus*, eats more than a million insects a year. The 20 million bats in Bracken Cave, Texas eat more than 250 tons (0.5 million lbs) of insects a night. Insects not eaten are often repelled from crops when they detect sonic pulses of bats. Each day, a little brown bat can eat its weight in insects. Bats in the Sacramento Valley feed on "moths, beetles and plant bugs that are often agricultural pests" (Long et al. 1998). Brazilian free tailed bats provide valuable pest control in cotton (Federico et al. 2008).

As a result of white nose syndrome, at least 1320 metric tons

Western corn rootworm, *Diabrotica* sp.

Courtesy Peggy Greb, USDA

(nearly 3 million pounds) of insects each year now escape predation, and the number will increase as more bats die. The value of bat predation in agriculture has been estimated at $22.9 billion each year. Biocontrols such as bats, reduce "the potential for evolved resistance of insects to pesticides and genetically modified crops" (Boyles et al. 2011).

One consequence of white nose syndrome could be increased use of pesticides. Current levels of pesticide applications have already caused extensive environmental degradation. Bees are seeing excessive mortality (Quarles 2011a; Hopwood et al. 2012). Wildlife habitat is being destroyed, and pesticides may be contributing to amphibian decline (Quarles 2011b; Pleasants and Oberhauser 2012; Relyea 2005).

What Can be Done?

Many of the suggestions, such as fogging caves with fungicides, heating caves, vaccination, and providing water seem impractical. Each year some infected bats survive and spread the fungus to new locations. If few bats were infected, then culling affected individuals might have some effect. But since large numbers are involved, culling may just hasten the destruction. Closing caves to tourists is possible, and might keep human activities from spreading the fungus to new locations. But the fungus is spreading from bat to bat, and closing caves might have little effect in the long run. The best idea is to boost bat health and immune systems by reducing their exposures to environmental toxins. Increased organic crop production would help prevent future exposures. Bat populations should also be closely monitored to follow the course of the disease (Foley et al. 2011; Hallam and Federico 2012).

Conclusion

Bats in the U.S. are dying from a fungus infection. The immune system of bats may have been weakened by pesticides and environmental pollutants. Combination of weak

Pesticides are killing honey bees.

Courtesy Kathy Keatly Garvey

immune systems and a virulent pathogen has led to lethal results. One study shows an association between sick bats and persistent pesticides. Other pesticides might be involved, but there is little information on the effects of modern pesticides on bats. Further research is needed, and white nose syndrome should be monitored closely. This kind of disturbance in an indicator species could be a sign of other problems in the U.S. ecosystem.

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Update

Happy Trails—Pheromones and the Argentine Ant

By William Quarles

The Argentine ant, *Linepithema humile*, recruits large numbers of foragers to a food supply through a trail pheromone. A trail pheromone is a reasonable consequence of the Argentine ant's biology. Recent sequencing of the genome reveals that this species should be very sensitive to tastes and odors (Smith et al. 2011).

Argentine ants are strongly attracted to (Z)-9-hexadecenal (Z-9), and it is present in whole body extracts (Cavill et al. 1979). For years Z-9 was thought to be the Argentine ant trail pheromone, mainly because ants readily follow artificial trails of Z-9 (Choe et al. 2012).

Since Z-9 has very low toxicity and is readily available commercially, researchers have tried various strategies to make Z-9 a component of ant management. For instance, a field trial showed that addition of Z-9 to sugar baits increased bait consumption by 33% (Greenberg and Klotz 2000).

A recent idea is to use Z-9 as a trail disruptant. In theory, saturating an area with false recruitment trails could disrupt the food supply, and reduce foragers following real trails into households (Suckling et al. 2011). A field test using an encapsulated spray formulation of Z-9 showed fewer visible foraging trails and fewer ants foraging at tuna baits for at least two weeks (Suckling et al. 2010).

The trail disruptant strategy was field tested with Z-9 dispensers over the course of two years in small 100 m^2 (1076 ft^2) garden plots. [Z-9 dispensers are commercially available for mating disruption of Asiatic rice borer, *Chilo suppressalis*.] Foraging trails were successfully disrupted, but Z-9 did not reduce population densities (Nishisue et al. 2010).

A similar long term experiment combined Z-9 dispensers with ant baits. Combination of Z-9 and ant baits led to foraging trail disruption and to lower ant populations than found with either baits alone or Z-9 alone (Sunamura et al. 2011).

Z-9 Not the Trail Pheromone

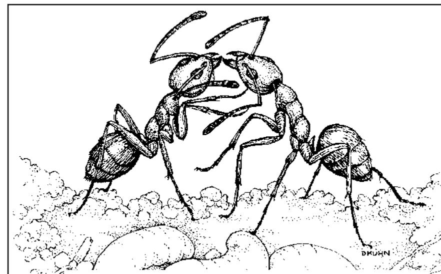
Despite the fact that Z-9 acts like a trail pheromone, and may be useful in pest management, it turns out that measurable amounts of Z-9 cannot be found in ant trails. Z-9 may be used by the ants to increase aggregation at food sources and at the nest. Major components of the natural pheromone are two iridoids, dolichodial and iridomyrmecin (Choe et al. 2012).

Water and Repellents Disrupt Trails

Foraging trails can also be disrupted by water baits in generally arid areas, and by repellents. Enzmann et al. (2012) found water sources drew Argentine ants out of structures, leading to formation of new foraging trails. Klotz et al. (1998) found that liquid boric acid baits around a perimeter were highly attractive, foraging trails increased at ant baits, ants were drawn out of structures and killed by baits.

Sprays of 1% essential oils such as peppermint, spearmint, wintergreen, cinnamon, and clove repel ants for one week. Spearmint is the most effective (Scocco et al. 2012). Shorey et al. (1992) found that farnesol was an effective Argentine ant repellent. Used as a barrier, it effectively excluded the Argentine ant from citrus trees for 7 weeks. When combined with Stickem™, it was effective for 17 weeks.

Combination of trail disruptants, baits, and repellents may provide an effective IPM strategy for reducing happy foraging trails of the Argentine ant.



Argentine ant, *L. humile*

Drawing by Diane Kuhn

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Calendar

January 22-25, 2014. 34th Annual EcoFarm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

February 3-6, 2014. Annual Meeting Weed Science Society of America. Vancouver, BC, Canada. Contact: www.wssa.net

February 27-March 1, 2014. 25th Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

March 9-11, 2014. California Small Farm Conference. Doubletree, Rohnert Park, CA. Contact: www.californiafarmconference.com

March 18-23, 2014. 4th Intl. Conf. Weeds and Invasive Plants. Montpellier, France. Contact: http://tinyurl.com/agsqucp

June 16-19, 2013. Annual Meeting Canadian Phytopathological Society. Edmonton, ALB. Contact: Kelley Turkington, Kelley.Turkington@agr.gc.ca

June 18-23, 2013. 70th Annual Convention, Pest Control Operators of CA. Harrah's, Las Vegas, NV. Contact: www.pcoc.org

June 26, 2013. California Certified Organic Farmers Postharvest Field Day. Pescadero, CA. Contact: www.ccof.org/education

August 4-9, 2013. 98th Annual Conference Ecological Society of America. Minneapolis, MN. Contact: www.esa.org

August 9-11, 2013. Workshop Northeast Organic Farming Association. UMass, Amherst, MA. Contact: www.nofa.org

August 10-13, 2013. Annual Conference American Phytopathological Society (APS). Austin, TX. Contact: Betty Ford, bford@scisoc.org or www.apsnet.org

August 11-14, 2013. Planning and Implementing Sustainable IPM Systems. Corvallis, OR. Contact: P. Jepson, jepsonp@science.oregon-state.edu

October 23-26, 2013. Pestworld, Annual Meeting National Pest Management Association (NPMA), Phoenix, AZ. Contact: NPMA, 10460 North St., Fairfax, VA 22031; 800/678-6722; 703/352-6762www.npmapestworld.org

November 10-13, 2013. Annual ESA Meeting. Austin, TX. Contact: ESA, 10001 Derekwood Lane, Suite 100, Lanham, MD 20706; 301/731-4535; http://www.entsoc.org

December 12-14, 2013. Acres USA Conference. Springfield, IL. Contact: www.acresusa.com

March 24-26, 2015. 8th Intl. IPM Symposium. Salt Lake City, UT. Contact: Elaine Wolff, Wolff1@illinois.edu

IPM News

Field Tests Show Grandevo™ Not Toxic to Honeybees

In the last issue of the *IPM Practitioner*, we reported that according to the label, Grandevo™ was toxic to bees. The EPA required that wording until field tests with bees were completed. Marrone Bio Innovations, Inc. (MBI), has now received U.S. EPA approval to delete the bee toxicity warning statement from its Grandevo Bioinsecticide label. The removal of the toxicity statement is supported by third-party field evaluations that show Grandevo has no increased mortality or detrimental effects to honeybees. The key study was conducted in central North Carolina during the summer of 2012. The month-long hive study compared the mortality rates of Grandevo to a known toxic pesticide reference treatment and a water treatment control.

The Grandevo maximum label rate of 3 pounds per acre (3.4 kg/ha) was applied on buckwheat pre-bloom and 7 days later at full bloom during bee flight. Bee mortality measured seven days after the initial application of Grandevo was not statistically different between the water treatment control group (30.0 bees per colony) and the Grandevo-treated group (24.1 bees/colony). At the same time, the mortality rate of the toxic pesticide used for comparison was 1808 bees per colony. Details about the Grandevo field trial in North Carolina are available in the April issue of *Bee Culture* magazine article or on the Marrone Bio Innovations website http://bit.ly/10QUwFJ.—*MBI Press Release, May 21, 2013*

European Union Bans Neonicotinoids

On Monday April 29, European Minister Tonio Borg said that the European Union would enact a two year ban on neonicotinoid pesticides. These pesticides, including imidacloprid, thiamethoxam, and clothianidan are extremely toxic to bees and are persistent in the field (see *IPMP* 33(1/2):1-11). When used as seed treatments, trace amounts are found in pollen and nectar, causing impaired bee performance. Deaths have occurred from acute exposure in the field, and storage of trace amounts by overwintering bees can lead to some of the symptoms of Colony Collapse Disorder and bee decline.—*New York Times, April 30, 2013*

USDA/EPA Release Report on Honeybees

On May 2, 2013 the USDA and the EPA released the *Report on the National Stakeholders Conference on Honey Bee Health*. This conference was held in Alexandria, Virginia on October 15-17, 2012. According to the report, bees are being impacted by pesticides, diseases, poor nutrition and other factors. These multiple factors are causing large losses of honey bee colonies each winter in the U.S.—*USDA, May 2, 2013*

Genetically Engineered Crops Resistant to 2,4-D Delayed

The USDA has decided to do a detailed environmental review of corn and soybean crops genetically engineered to resist applications of 2,4-D. These crops are the agribusiness answer to herbicide resistant weeds caused by use of glyphosate tolerant Roundup Ready® crops (see *IPMP* 33(3/4):1-9). The USDA review could take up to two years.—*New York Times, May 11, 2013*

New Website Promotes EcoWise Certified

A new website funded by a California Department of Pesticide Regulation grant can be found at www.gotantsgetserious.org. This website encourages consumers to use IPM methods for ant management. Consumers wanting to hire IPM certified companies that emphasize non-chemical methods, protect water, and minimize pesticide applications are provided with a direct link to the EcoWise Certified website www.ecowisecertified.org.—*Bill Quarles*

Conference Notes

Special Pheromone Report—ESA 2012 Annual Meeting

by Joel Grossman

These Conference Highlights were selected from about 1,800 talks and over 600 poster displays at the Nov. 11-14, 2012, Entomological Society of America (ESA) annual meeting in Knoxville, Tennessee. ESA's next annual meeting is November 10-13, 2013, in Austin, Texas. For more information contact the ESA (10001 Derekwood Lane, Suite 100, Lanham, MD 20706; 301/731-4535; www.entsoc.org

Pheromones in Bangladesh

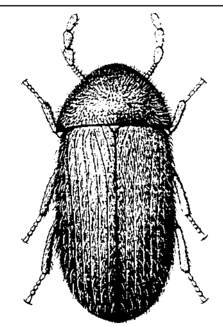
In Bangladesh, seedlings are given a healthy start with soil amendments such as mustard oil-cake, poultry refuse and *Trichoderma* composts, some of which are produced and sold by local farmers, said Rangaswamy Muniappan (Virginia Polytechnic Instit, 526 Prices Fork Rd, Blacksburg, VA 24061; rmuni@vt.edu). A combination of pheromone traps and hand-picking reduces cole crop damage from leafeating caterpillars by 80%. This action boosts cabbage yields 22%, increases economic returns 32% and reduces pest control costs over 75% by eliminating most pesticide use.

Trapping fruit flies with indigenous lures and pheromones instead of spraying pesticides boosts cucurbit yields 200%-300% and reduces damage 90%. Cuelure, a synthetic mimic of the pheromone produced by the female melon fly, *Bactrocera cucurbitae*, is used in traps to protect cucumbers, melons and gourds. Pheromone use has increased fruit fly catches 15- to 18-fold over using mashed gourd as an attractant; though both types of attractant traps can be used together.

According to the Integrated Pest Management Collaborative Research Support Program (IPM CRSP): "Before cuelure, pesticides were applied on a weekly basis, costing the farmers more to produce the vegetables than they were making through sales...With cuelure, damage caused by fruit flies went down 70%, and farmers have been making a profit... After just a few seasons with the new technique, Bangladeshi cucurbit farmers are making three times what they made before using cuelure... Since 2003, over 47,000 farmers in Bangladesh have attended farmer field schools as well as farmer training and field days in Bangladesh. These events are essential in promoting the widespread use of new pest management methods such as pheromone traps."

Cigarette Beetle Mating Disruption

One of the most common dry food factory and warehouse beetle pests, the cigarette beetle, *Lasioderma serricorne*, feeds on milled, packaged and processed grain-based products and spices, as well as yeast and flower nectar, said Rizana Mahroof (South Carolina State Univ, 300 College St NE, Orangeburg, SC 29117; rmahroof@scsu.edu). The synthetic sex pheromones serricornin (4,6-dimethyl-7-hydroxynonan-3-one) and anhydroserricornin (2,6-diethyl-3,5-dimethyl-3,4-dihydro-2*H*-pyran), produced by adult females and attractive to adult males, are currently used mostly for monitoring in IPM programs. But they can also be used for mass trapping and mating disruption.



Cigarette beetle, *Lasioderma serricorne*

Mating disruption is a highly selective pest control method, and dispenser systems leave no detectable residues. Mating disruption dispensers generate a pheromone fog that eliminates male moths in the early stages of infestations. In 2010 and 2011, Trécé mating disruption dispensers deployed at the rate of one per 225 ft^2 (25 m^2) were tested in South Carolina feed mills, flour mills and seed warehouses. Results were monitored with sticky traps and oviposition cups. Microscopes were used to distinguish cigarette beetles from drugstore beetles, *Stegobium paniceum*, the two most common stored product beetles in the Southeastern United States.

In 2010, cigarette beetles were significantly reduced 8 weeks after mating disruption treatments, and 27 insects were caught. In 2011, cigarette beetles were significantly reduced 2 weeks after mating disruption treatments, and 3 insects were caught. Thus, pest population reductions from mating disruption treatments in 2010 carried over to 2011; 2012 results are being evaluated. Also, since "beetles are different than moths," new dispensers and pheromone isomer blends are being developed.

Flour Beetle Traps

"Insect traps are used for detecting and monitoring *Tribolium castaneum*, the red flour beetle, which is a major pest of grain processing and storage facilities," said Nisha Shakya (Oklahoma State Univ, 127 Noble Res Center, Stillwater, OK 74078; nisha.shakya10@okstate.edu). Three types of monitoring traps were compared: Dome™ (Trécé, Adair, OK) with kairomone and pheromone lure; ClimbUp® BG (Black Grip) with corn oil as kairomone; and Torios®(Fuji Flavor Co, Japan) with pheromone lure and sticky surface.

Dome™ traps, which are marketed commercially by Trécé to monitor red flour beetle, caught the most beetles. There was no significant difference between ClimbUp BG and Torios traps.

Stored Product Moth Mating Disruption

Three major pheromone strategies to combat stored product moths are: 1) Attract and kill 2) Mass trapping and 3) Mating disruption, said Charles Burks (USDA-ARS, 9611 S. Riverbend Ave, Parlier, CA 93648; charles.burks@ars.usda.gov). Which strategy to use depends on population density and environmental conditions.

Mating disruption mechanisms, as put forward by Stelinski et al. (2004) for tortricid moths in fruit orchards, include: 1) camouflage of female-produced plumes, 2) false-plume-following by male moths, and 3) habituation of CNS (central nervous system) or peripheral receptor adaptation.

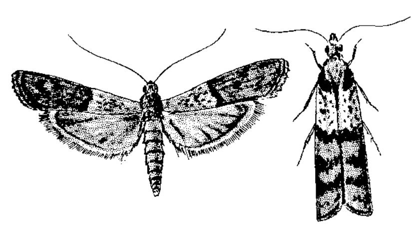
Knowing which mechanism of mating disruption is operative for a particular pest moth species aids in making practical choices in mating disruption programs: such as whether to use high strength (Trécé's CIDETRAK® IMM), medium strength (BASF's Allure®) or natural strength (Suttera's CheckMate® puffer) pheromone emitters.

Temperature and available free water or humidity affect pheromones and pest control. Interactions with environmental variables and pheromone mating disruption sometimes result in delayed or postponed moth mating. Indeed, just keeping male and female moths apart for a sufficiently long time period may even be enough to drive down mating and pest populations.

"Effects that are small without delayed mating can be synergistic when delayed mating is considered," said Burks. For example, hydration and pheromone mating disruption synergize and can increase Indian meal moth, *Plodia interpunctella*, or navel orangeworm, *Amyelois transitella*, mating disruption by 95%.

Temperature is also important. With Trécé's hand-applied CIDETRAK® IMM mating disruption devices, there is more Indian meal moth mating disruption at 27.5°C (81.5°F) than at 20°C (68°F). At 28°C (82.4°F), there is a 96% reduction in fertile moth eggs at 4 days (Huang & Subramanyam, 2003).

"You get more bang for the buck at higher temperatures" for Indian meal moth mating disruption, said Burks. Attract-and-kill and mass trapping may work better against Indian meal moth at lower temperatures and low populations. This is because Indian meal moths find each other and mate quickly after emergence of adult from pupae.



Indian meal moth, *Plodia interpunctella*

NOW Long Lasting Lures

"The navel orangeworm (NOW), *Amyelois transitella*, sex pheromone has posed particular problems for chemical ecologists in terms of identification of minor components, and subsequently, stabilization in a lure for monitoring purposes," said Bradley Higbee (Paramount Farming, 33141 Lerdo Hwy, Bakersfield, CA 93308; bradh@paramountfarming.com). Although the main pheromone component is used successfully to disrupt mating in almonds, it is not sufficiently attractive for use as a monitoring tool.

The lack of available monitoring tools has been a limiting factor in the ability to effectively identify phenological time point, compare relative NOW populations and effectively manage NOW in almonds and pistachios. But recently discovered pheromone components have now been formulated into an effective product. Modified wing traps and delta traps were baited with virgin female NOW moths as pheromone sources, as well as with Suterra membrane lures with 1-2 mg blends of either 3 or 4 NOW pheromone components.

"All lures trapped comparable numbers of male NOW relative to virgin-baited traps for at least 4-5 weeks in almond orchards," said Higbee. General Mixed-Effects Models (GLMMs) indicated that the four-component blend with a 2 mg load generally outperformed the other lures. Thus, "the Suterra membrane dispenser provides a long lasting platform for release of the NOW pheromone blend," said Higbee.

Mass Trapping and Monitoring NOW

"Navel orangeworm (NOW), *Amyelois transitella*, is a major pest of almond, *Prunus dulcis*; pistachio, *Pistacia vera*; and walnut, *Juglans regia* grown in California's Central Valley," said Elizabeth Boyd (California State Univ, 400 W. First St, Plumas 225, Chico, CA 95929; eaboyd@csuchico.edu). "A novel bait, placed in a sticky bottom wing trap, was developed and utilized for monitoring and mass-trapping of NOW in almonds and pistachios (Nay et al. 2012). In almonds, most chemical management of NOW centers around the susceptible hull spit stage of the developing fruit." This is when female NOW moths lay eggs and neonate larva enter the fruit, causing 1-10% damage in 'Nonpareil' almonds.

"Timing of chemical treatments for NOW at hull split have traditionally followed degree day (DD) calculations, various egg counting methodologies, or a 'shoot from the hip' strategy," said Boyd. "However, these strategies for predicting treatment timing do not predict end-season damage levels. The objective of this research was to explore the use of the novel baited mass-trapping system as a monitoring, treatment timing, and end-season damage predictive tool." However, 2011 was a low NOW year; and almond damage levels at hull split were low, even when no insecticides were used.

This fact "highlights the need for understanding NOW overwintering population levels," which are lowered by good orchard sanitation practices (i.e. removing leftover unharvested nuts), said Boyd. If 1% nut damage was acceptable, "our model would predict that a grower implementing mass trapping would time an insecticide application during hull split when pre-hull split trap captures reach an average of 2 moths per trap.

Citrus Leafminer Mating Disruption

Citrus leafminer (CLM), *Phyllocnistis citrella*, mating disruption involves a noncompetitive mechanism, the creation of a sensory imbalance, which makes the pheromone blend ratio crucial, said Craig Keathley (USDA-ARS, 2001 S. Rock Rd, Fort Pierce, FL 34945; craig.keathley@ars.usda.gov). Low rates of a 3:1 blend of (Z,Z,E)-7,11,13-hexadecatrienal/(Z,Z)-7,11-hexadecadienal in SPLAT-CLM (ISCA Technol) were machine sprayed into tree canopies as 1-gram dollops at a rate of 500 grams per ha (0.4 acres).

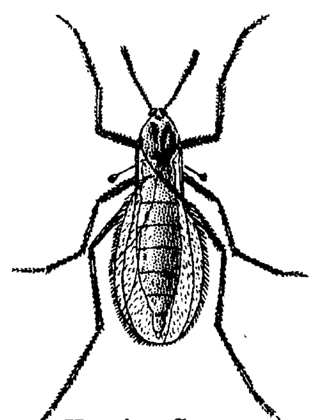
Some plots were treated with SPLAT-CLM both in winter and spring. Other plots were treated only once, either in spring or winter. Results were compared to plots that received no pheromone. The SPLAT-CLM winter application was on February 8, when overwintering CLM were emerging to attack the hot new citrus growth flushes. The SPLAT-CLM spring application was on April 24.

Mating disruption effectiveness was estimated from delta trap catches. Moth flights peaked in late March, and leafmines peaked in late May. Immigration of moths from outside the orchard was suspected.

Trap catches showed significant mating disruption from spring SPLAT-CLM applications. There was no interaction between winter and spring mating disruption applications.

Pheromone Traps Monitor Hessian Fly

Oklahoma produces about 6 million acres (2.4 million ha) of winter wheat, *Triticum aestivum*, annually for grain and livestock forage, increasingly using no-tillage to reduce costs and soil erosion while increasing nutrient and moisture retention, said Nathan Bradford (Oklahoma State Univ, 127 Noble Res Center, Stillwater, OK 74078; nathan.bradford@okstate.edu). "However, increases in no-till wheat acreages have been linked to increases in Hessian fly, *Mayetiola destructor*, numbers across the state."



Hessian fly, *Mayetiola destructor*

"It is thought that the wheat stubble leftover after harvest provides Hessian fly puparia a place to overwinter that would normally have been tilled," said Bradford. "In no-till systems, because the stubble is left unburied the puparium have a much greater chance of survival."

During the 2011/2012 winter wheat growing season, sticky cards (Pherocon® VI Liners) equipped with synthetic Hessian fly pheromone (Pheronet Mayetiola Destructor Lure) were placed in selected locations across the major wheat growing regions of Oklahoma. There were two traps per site and cards containing the synthetic pheromones were changed bi-weekly and numbers of Hessian fly were recorded.

Hessian flies were trapped in small numbers in October and November, and in larger numbers during the spring months of March, April and May. Maximum trap catch in a sampling period was 1,400 flies. Pheromone traps did not detect Hessian flies during the extreme winter (Dec.-Feb.) and extreme summer months (June-Sept.). These observations indicated two flight periods and two generations of flies in Oklahoma.

"A prudent IPM plan relies on an extensive database of a pest's characteristics and behavior in order to best manage the organism," said Bradford. Pheromone trap catch monitoring data may prove useful in timing foliar sprays and targeting adult Hessian flies on winter wheat plants during the extended spring flight period.

SPLAT Lures for Fruit Flies

"Current Male Annihilation Techniques (MAT) combine male-specific attractants with insecticide in traps and devices that, while effective, require routine service that is costly and labor intensive," said Lyndsie Stoltman (ISCA Technol, 1230 Spring St, Riverside, CA 92507; lyndsie.stoltman@iscatech.com). "Specialized Pheromone and Lure Application Technology (SPLAT) was initially developed for mechanical deployment of small doses of Lepidopteran pheromones for long-lasting mating disruption."

"A U.S. EPA review has certified all inert ingredients in SPLAT to be 'suitable for food use,' with several formulations labeled as organic," said Stoltman. SPLAT is "hand or mechanically applied, rain-fast, and provides long-term controlled release." For Oriental fruit fly, *Bactrocera dorsalis*, SPLAT MAT Spinosad ME combines spinosad with methyl eugenol. SPLAT Anarosa combines spinosad and a feeding stimulant for Mexican fruit fly, *Anastrepha ludens*.

In Brazil, SPLAT MAT Spinosad ME and SPLAT MAT Malathion ME combine a pesticide and methyl eugenol against carambola fruit fly, *Bactrocera carambolae.* A single application of SPLAT MAT Spinosad ME promotes sustained suppression of *B. carambolae* populations for four months. In areas with high pest pressure, the number of points per area can be increased while the size of each point is decreased. For lower pest densities, the number of points may be decreased while size is increased. In both scenarios the total active ingredient applied is equal.

Walnut Twig Beetle Pheromone Traps

To optimize early detection methods, Tennessee and California WTB flight responses were compared vis-a-vis male-produced pheromone, funnel traps, window-type bottle traps and ethanol-treated walnut branches. "Trap catches in California far exceeded those in Tennessee," said Paul Dallara (Univ of California, One Shields Ave, Davis, CA 95616; pdallara99@yahoo.com). "In two of three studies in TN, the WTB aggregation pheromone (developed in CA) elicited a significant flight response from both sexes of WTB when dispensed at a range of release rates."

Comparisons of traps in TN showed that 2-liter bottle traps baited with WTB pheromone were more efficient than 4-unit Lindgren funnel traps, catching more WTB per unit area. But the funnel traps caught more WTB.

"In both CA and TN, when combined with a pheromone bait, an ethanol-treated black walnut branch section elicited a significantly greater flight response from both sexes of WTB than did the pheromone bait alone," said Dallara. "Trap catches in CA to the pheromone bait plus ethanol-treated branch section increased with time in the field, suggesting that quantitative or qualitative changes in semiochemicals from the ethanol-treated branch section were occurring over the 30-day test periods."

Pheromone Isomer Brew Disrupts Mating in Hops

Adult California prionus, *Prionus californicus*, are large longhorned beetles (Cerambycidae) pestiferous on Western USA apples, cherries and hops, as well as many other agricultural and ornamental crops, said James Barbour (Univ of Idaho, 29603 U of I Lane, Parma, ID 83660; jbarbour@uidaho.edu). Adults emerge in late June in the Pacific Northwest. In July-August, before their 3-week adult lifespan is over, females lay up to 200 eggs at the soil line. The larvae chew on roots underground for 3-5 years, and wreck hops plants.

Adult female *P. californicus* are sedentary. So, light traps capture the males during their dusk to midnight flights. Adults do not feed or drink during their 3-week lifespan, and thus need to find mates quickly.

The sex pheromone is (3R,5S)-3,5-dimethyldodecanoic acid plus some minor components. The synthetic sex pheromone is a mixture of enantiomers. But in the field a mixture of (3S,5R) and (3R,5S) synthetic isomers formulated into 100 mg lures works well, with no inhibition. The synthetic isomer mixture also captures *P. integer*.

Given the short adult lifespan of *P. californicus*, pheromone mating disruption is needed for only a very short time on this high-value beer brewing specialty crop. In small plot tests, mating disruption provided 84% suppression of *P. californicus*. In 25-100 acre (10-40 ha) Idado and Washington hopyard trials, pheromone dispensers for mating disruption are being placed on poles.

Emerald Ash Borer Traps

"Various trap designs and lure formulations for emerald ash borer (EAB), *Agrilus planipennis*, have been developed and evaluated in field trials," said Jacob Bournay (Michigan State Univ, 288 Farm Lane, Rm 42 Nat Sci, East Lansing, MI 48824; bournayj@msu.edu). "Many of these trials were conducted in sites with moderate to high EAB densities, where substantial number of beetles are captured per trap. At these densities, stress-related volatiles emitted by infested ash trees likely compete with lures. Moreover, as canopies thin and dieback becomes apparent, light penetration through the canopy changes, potentially affecting EAB visual responses to traps."

"The EAB population in a given area can be characterized as an invasion wave," said Bournay. "Crest sites represent areas where EAB densities are at peak levels, most trees are heavily infested and declining. Core sites represent sites invaded early, where most ash trees have been killed and EAB populations have largely collapsed. Cusp sites represent recently invaded areas where EAB populations are relatively low and few trees show any evidence of infestation. Ideally, evaluation of traps and lures should occur in Cusp sites because they represent conditions where EAB detection is a viable objective."

Along an east-west gradient across southern Michigan with Cusp, Core and other invasion stages represented, EAB traps and lures with semiochemicals were tested. Canopy traps included green prism traps with three clear panels coated with clear Pestick® to capture insects. Both purple and green funnel traps with collection cups at the base and Fluon coating were tested. Double decker traps were composed of two purple prism traps. Lures included manuka oil (Synergy Semiochem Corp), cis-3-hexenol and cis-lactone (released from rubber septa, and believed to be a pheromone).

"Overall, double-decker traps baited with cis-3-hexenol and manuka oil and double-decker traps with cis-3-hexenol plus cis-lactone lures captured more EAB than the green and purple funnel traps, both baited with cis-3-hexenol plus cis-lactone," said Bournay.

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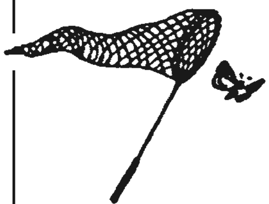

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