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PEST CONTROL QUARTERLY

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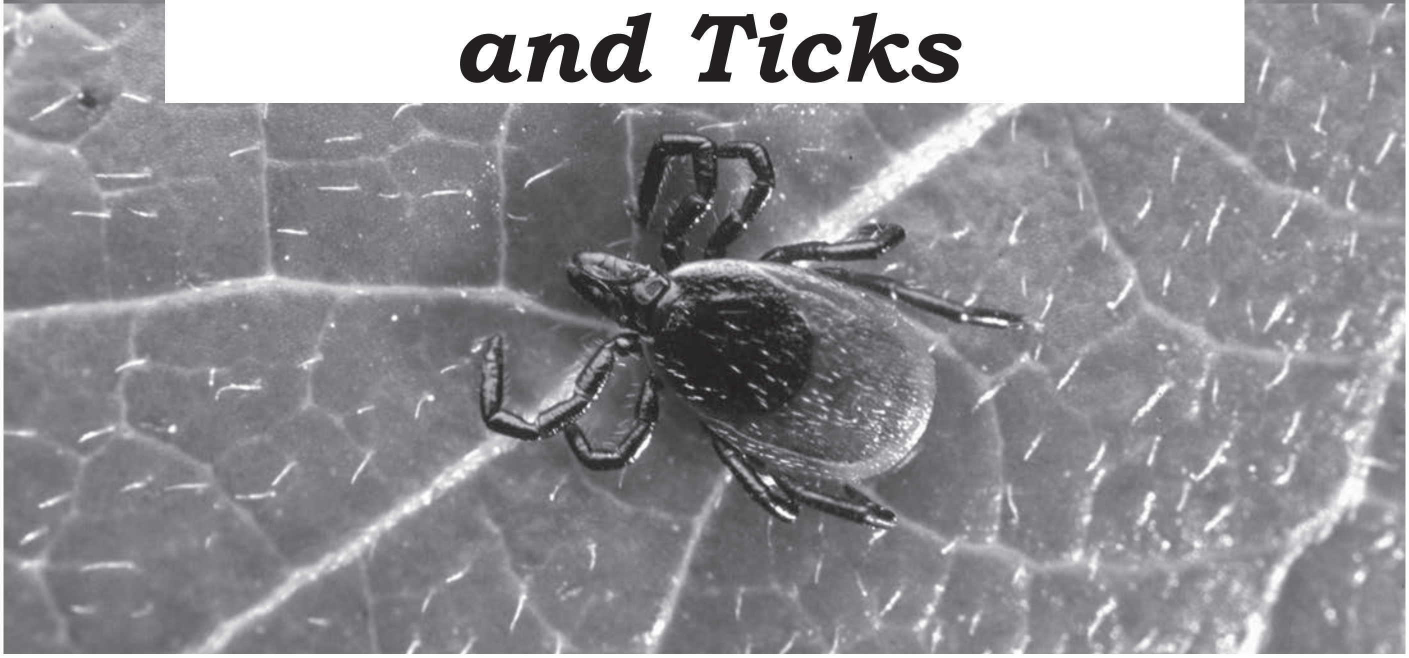
Stopping Mosquitoes and Ticks

Photo courtesy of CDC and James Gathany



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An Invitation to Join

B · I · R · C

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BIRC, A NON-PROFIT CORPORATION, WAS FORMED IN 1979 to provide practical information on the least-toxic methods for managing pests. The interdisciplinary BIRC staff and an international network of advisors and research associates have designed highly effective alternative solutions to a wide variety of pest problems throughout the world. This work has been based on the principles of 'Integrated Pest Management' or 'IPM'.

IPM IS A DECISION-MAKING PROCESS that considers the whole ecosystem in determining the best methods for managing pests. The objective of an IPM Program is to suppress the pest population below the level that causes economic, aesthetic, or medical injury. IPM strategies are designed to be the least disruptive of natural pest controls, human health, and the general environment. Horticultural, physical, mechanical, biological, least-toxic chemical, and educational tactics are integrated to solve pest problems with a minimal reliance on pesticides.

THE IPM APPROACH HAS GAINED FAVOR with government and business because it is cost-effective. Community groups and pest management professionals are enthusiastic about IPM programs because the use of toxic materials is reduced while better pest control is achieved.

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Preventing Mosquito-Borne Diseases

By William Quarles

Worldwide, one in 17 people will die from a mosquito-borne disease. Until recently, the U.S. has been spared much of this extreme pain and suffering. But now global warming, worldwide travel, and other factors have led to an increase of mosquito-borne pathogens. New diseases in the U.S. include West Nile fever (1999), chikungunya (2014), dengue (2005), and Zika (2016). There has also been a minor U.S. resurgence of malaria (Chan et al. 2016; Epstein 2000; Epstein 2005; Epstein 2007; CDC 2017a; Quarles 2016; Olkowski 2001).

Chikungunya and dengue (breakbone fever) involve painful symptoms, and Zika virus infection can lead to birth defects. So far, the number of cases have been limited. About 5,000 Zika cases were reported in the U.S. in 2016, with another 36,000 cases in U.S. territories (CDC 2017b). About 12,000 U.S. cases of West Nile fever are seen each year, with 2,300 serious illnesses, and about 84 deaths (Quarles 2010). Though numbers are relatively small, increases are expected as global temperatures rise (Chan et al 2016; Epstein 2005; Quarles 2017; Quarles 2007).

These new diseases have brought greater challenges to mosquito control agencies. Until recently, attention has been focused on floodwater and saltmarsh mosquitoes with known and limited breeding areas, such as catchwater basins and tidal plains (Faraji and Unlu 2016). But warmer temperatures have brought expanded ranges for container breeding mosquitoes such as the yellow fever mosquito, *Aedes aegypti*, and the Asian tiger mosquito, *Aedes albopictus* (Kraemer et al. 2015; Hahn et al. 2016). For example, these mosquitoes have been found recently in 85 California cites (Metzger et al. 2017).

Photo courtesy CDC and James Gathany

***Aedes aegypti* mosquitoes carry chikungunya, dengue, and Zika viruses.**

Photo courtesy CDC and James Gathany

The Asian tiger mosquito, *Aedes albopictus*, breeds in containers of water. It can carry many pathogenic viruses.

Containers around residences provide many points of origin for mosquitoes, and are generally inaccessible to mosquito abatement districts. Stopping both floodwater mosquitoes and container breeders has strained the resources of many local agencies, and has led to widespread pesticide sprays when outbreaks occur (Faraji and Unlu 2016).

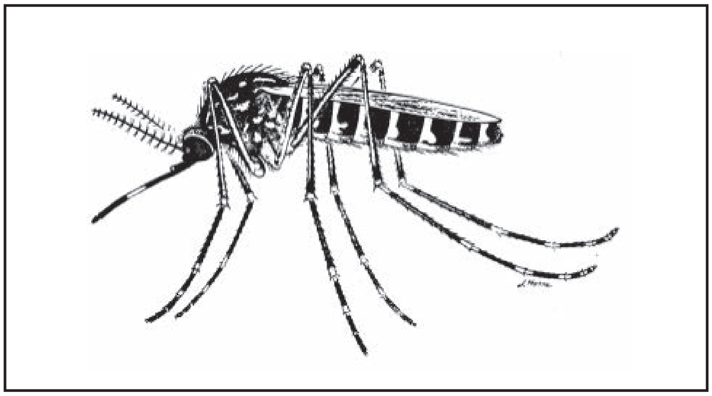
This article outlines an IPM program that will reduce mosquito populations and biting without polluting the environment and destroying beneficial organisms. Mosquito bites can be reduced through source reduction, larval control, traps, exclusion, baits, and personal protection including repellents.

Mosquitoes that Cause Disease

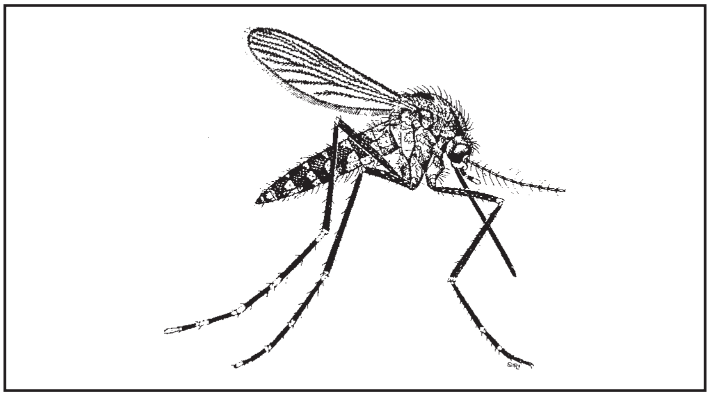
Anopheles freeborni and *Anopheles quadrimaculatus* carry malaria in the U.S. Malaria is caused by a protozoa. Most other mosquito-borne diseases are caused by viruses. The common house mosquito, *Culex pipiens*, carries West Nile fever and St. Louis encephalitis. *Aedes aegypti* and *Aedes albopictus* carry yellow fever, dengue, chikungunya, viral encephalitis, and Zika. *Ae. albopictus* may also vector 13 other viruses, including West Nile virus (Vanlandingham et al. 2016).

Each pathogenic mosquito species has its own behavior and lifestyle (see Box A). *Aedes* spp. tends to bite outside in the daytime. *Anopheles* spp. bites inside at night. *Culex* spp. bites inside or outside, usually at sunset or night. *Anopheles* tends to bite only humans, *Culex* bites a large number of species. So risks of West Nile infection increase outside at night, and risks of Zika increase outside in the daytime (Service 1980; Chan et al. 2016).

Some *Aedes* species such as *Ae. aegypti*, and *Ae. albopictus* have a limited flying range from their breeding sites, 100-300 yards. But salt marsh mosquitoes such as *Ae. sollictans* or *Ae. taeniorhynchus* may fly 5-40 miles. Ranges of *Culex* spp. and *Anopheles* spp. are often less than a mile. Larval control measures have to be focused on breeding sites, whether nearby or distant (Swiger 2016).



***Culex tarsalis* carries West Nile virus.**

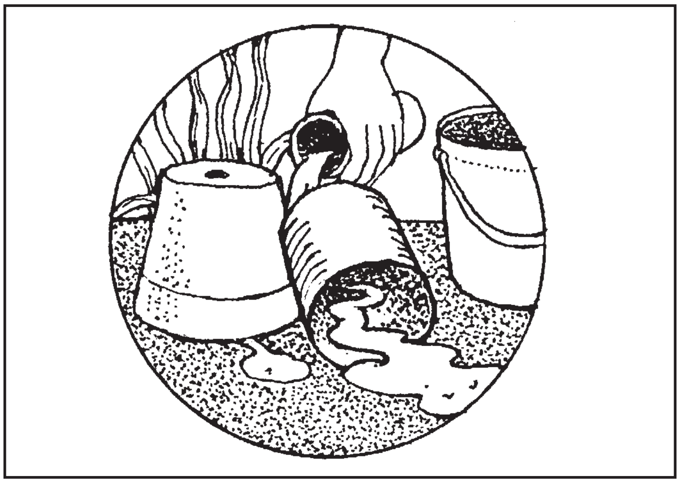


The treehole mosquito, *Aedes sierrensis.*

Source Reduction

Mosquitoes lay eggs in water or near water (see Box A). Stopping them involves elimination of breeding sites and larval control methods. Since they breed in water, elimination of water sources can relieve biting pressure. Mosquito control districts do limited source reduction by improving drainage in swamps and other areas. But drainage is sometimes too disruptive of wildlife, and if monitoring shows a mosquito problem, the pond or pool can be treated with *Bacillus thuringiesis israelensis* (BTI) or an insect growth regulator (IGR) to stop larval development (see below) (Olkowski 2001).

With the increased importance of container breeders, addressing home water sources now has critical importance. Sources include bird baths, cisterns, clogged roof gutters, dripping outdoor faucets, old tires, drain outlets from water conditioners, ornamental ponds, overwatered lawns, rain barrels, saucers under potted plants, tin cans, jars, and watering cans. Just about anywhere that water can collect outside provides a possible breeding source for mosquitoes. Water in containers should be emptied, bird bath water changed often, gutters cleaned, and faucets fixed. Old tires should be discarded. Ornamental ponds can be stocked with mosquito fish or treated with formulations of BTI Mosquito Dunks® (see Resources). Treeholes can be treated with Mosquito Dunks or methoprene briquets (Altosid®) (see Resources). When the treehole is dry, breeding cannot occur, when wet, BTI or methoprene briquets will kill developing larvae (Olkowski et al. 1991; Olkowksi 2001).



Drawing by Diane Kuhn

Containers of water should be emptied, and ornamental ponds treated with BTI or stocked with mosquito fish.

Mosquito Fish

Many mosquito control districts will supply mosquito fish such as *Gambusia affinis* free of charge. These fish can be used to stock ornamental pools or other backyard bodies of water that are isolated from general drainage into local waterbodies. *Gambusia* should be kept out of local waterbodies because it will compete aggressively with other fish, and could lead to declines of other species, making mosquito problems worse. In areas with cold winters, the fish will probably have to be restocked every year (USGS 2017).

Larval Control Microbials

Mosquitoes should be controlled in the larval stage. The commercial development of *Bacillus thuringiensis israelensis* (BTI), marketed as Teknar® and Vectobac® (see Resources) offers the possibility of a least-toxic suppression agent that is also highly selective. This pathogen, like other strains of BT, acts initially and perhaps primarily as a stomach poison, damaging cells of the midgut epithelium of infected mosquito larvae. BTI works best on early stage larvae that are actively feeding (Alameda 1999; Federici 1995).

In comparison with other bacterial toxins and even many synthetic insecticides, BTI has an extremely rapid lethal action on mosquito larvae. Studies show that a moderate-to-high concentration kills about 50% of a test population of some *Culex* mosquito species in 15 minutes and the rest of the population in about an hour. Furthermore, only a five-minute exposure to the toxin is necessary for death to occur later. *Culiseta* and *Aedes* species require longer exposure and higher doses than *Culex* to be effective. *Anopheles* appear to be the least susceptible of the mosquitoes tested (Levy et al. 1984).

Anopheles is susceptible to formulations of the related bacterium *B. sphaericus*. Formulations such as VectoLex® are useful for treating larvae of *Culex* spp. and other mosquitoes found in polluted water (see Resources) (Mulla et al. 1997). VectoLex also gives good control of *Aedes triseriatus*, the predominant species found in waste tire dumps (Siegel and Novak 1997).

Box A. Mosquito Biology

The only area in the world where mosquitoes are absent is Anarctica. These ubiquitous, two-winged insects are part of the insect order Diptera and belong to the Culicidae family. There are 3 subfamilies—Toxorhynchitinae, Anophelinae, and Culicinae. Mosquitoes of the first subfamily are not generally pests, and their larvae actually eat pest mosquito larvae. The most important pest genera include *Anopheles*, *Culex*, *Aedes*, *Mansonia*, *Haemagogus*, *Sabethes* and *Psorophora*. All mosquitoes go through complete metamorphosis including egg, larval, pupal and adult stages.

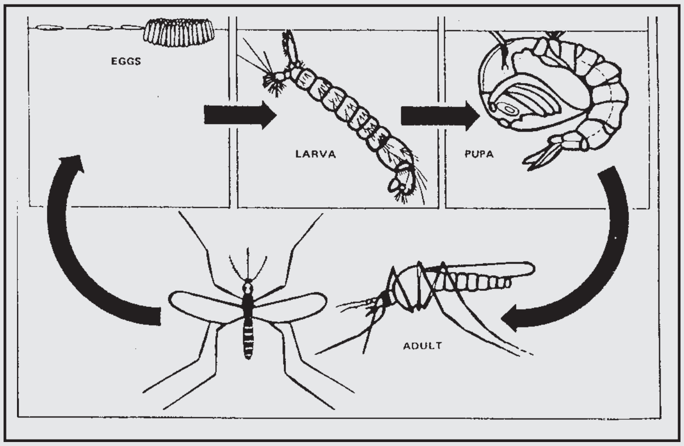
Adult mosquitoes are small, slender insects of about 4 to 6 mm (1/4 in) length. Males have feathery antennae, those with short antennal hairs are females. An important mosquito characteristic is the long, slender proboscis that is used to penetrate skin. Males do not suck blood, females feed on blood in order to produce eggs. Unfed females are slender; those with blood meals have a red, swollen appearance; those carrying eggs have a swollen, whitish appearance.

Females lay between 30 to 300 brown to blackish eggs at one time in a water habitat. *Anopheles* lay single, oval shaped eggs that float on the water. *Culex* and some *Mansonia* eggs are also laid on the water, but are deposited in the form of rafts. Eggs of these three species cannot survive desiccation.

Aedes, *Psorophora* and *Haemagogus* lay their eggs in damp places just beyond the water line. Some *Aedes* prefer tree holes, clay pots and other containers. *Aedes* and *Psorophora* eggs can withstand weeks or years of desiccation, and can survive cold weather. Hatching is triggered by alternate cycles of flooding and drought, and not all the eggs hatch at the same time. These mosquitoes tend to be timed-release pests and never go away without good control measures.

Most mosquito larvae must come to the surface to breathe. They are most vulnerable at this time, and this is the reason that much mosquito control work focuses on the larval stage. *Anopheles* larvae lie parallel to the water surface and breathe through the holes in their sides called spiracles. Culicine larvae hang from the surface at an angle and breath through a siphon tube. Larvae filter-feed on micro-organisms and organic matter. Many species spend 5-7 days in the larval stage.

Mosquitoes can develop anywhere there is standing water. The range of habitats is wide. Fresh water, salt water, brackish water, ground pools, wells, cesspools, marshes, containers, tires, tree holes, and aquatic vegetation are all areas where mosquitoes can develop. *Anopheles* species generally prefer clean, unpolluted water. Many *Aedes* species develop in tree holes or containers. *Culex* tends to prefer polluted water associated with poor drainage and sanitation. *Psorophora* breeds in rice fields and marshy meadows. *Mansonia* mosquitoes are associated with aquatic vegetation. *Haemagogus* is a forest species in the U.S. (Service 1980).



Life stages of mosquitoes are eggs, larvae, pupae and adults. Eggs, larvae, and pupae are found in water.

Feeding Habits

Not all female mosquitoes feed on human blood. Toxorhynchitinae are all vegetarians. The two big mosquito pest groups are the anophelines and the culicines. Most pest mosquitoes are culicines that attack whatever hosts are available, feeding on humans, other mammals, birds, and even reptiles. Many *Culex* prefer to feed on birds, but will feed on humans if necessary. Species that prefer to feed mainly on animals other than humans are called zoophilic. Anophelines usually prefer to feed on humans. Mosquito species with this preference are called anthropophilic.

Many *Anopheles* species prefer to bite inside houses. *Aedes* feeds outside, and tends to rest outside before and after eating. *Culex* will feed either inside or outside.

Most *Culex*, *Anopheles* and *Mansonia* mosquitoes bite at night. *Aedes* tends to feed in the day or early evening. *Psorophora* and *Haemagogus* bite outside during the daytime.

Anopheles hunt, mate, bite and lay eggs at night. African anophelines tend to bite inside houses after 11 PM. South American anophelines tend to dine earlier than 9 PM, and tend to bite outside houses. When and what host any mosquito bites, though, depends on what is available. If few humans are available, anthropophilic species will temporarily become zoophilic.

Switching of hosts has implications for human disease. *Culex* species are able to bring encephalitis virus from birds to humans. *Aedes* species bring yellow fever virus from monkeys to humans. Since *Anopheles* concentrates on humans, it will transmit at high frequency any human pathogen that it is able to incubate (Service 1980).

In field studies BTI has been shown to be effective against several mosquito species in widely differing water quality conditions, including irrigated pastures, storm drains, ponds, dairy lagoons, and salt marsh potholes. BTI has also been shown to be effective against many black fly (Simuliidae) species, while also being nontoxic to most other aquatic species. BTI can be applied with conventional application equipment. Although it is more costly than more toxic and less selective products, the added costs of using BTI should be weighed against the damage to non-target wildlife resulting from use of other products (Levy et al. 1984; Federici 1995; Lacey 2007).

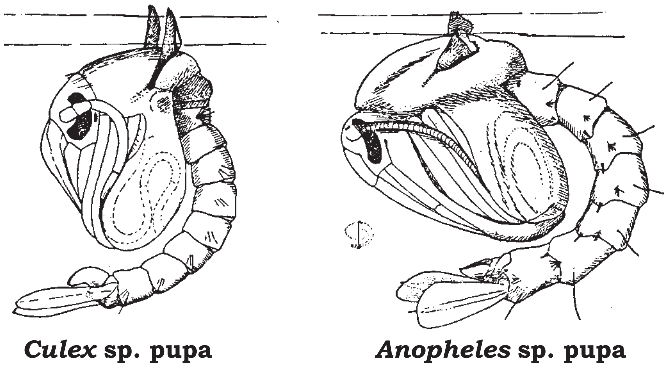
Larval Control IGRs

Insect growth regulators (IGRs) have low toxicity and can provide larval control. An example is methoprene, which was first introduced for mosquito control in 1974. It now marketed as Altosid® (see Resources). This IGR offers greater selectivity and less toxicity to non-target wildlife than most other conventional insecticides. It induces damaging morphological changes in second, third and fourth instar mosquito larvae, resulting in the failure of adult mosquitoes to emerge from pupae. It is most effective on the 4th stage larvae (Alameda 1999; Mulla 1995). Use of methoprene on 4th stage larvae allows earlier stages to remain in streams to feed fish and waterfowl (Service 1995). Packaged in slow-release briquets, it is effective for at least 30 days in standing water. Altosid® XR briquets supplied methoprene for 1.5 years in Minnesota (Boxmeyer et al. 1997). It can be coated on sand for easier foliage penetration, or applied as a spray solution from air or ground.

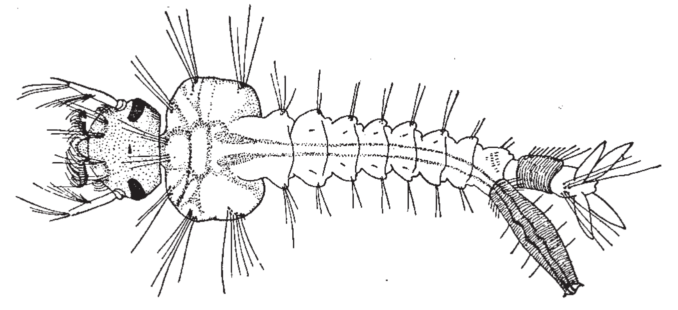
Methoprene has an acute oral LD50 in rats of >34,000 mg/kg, indicating a high degree of safety to mammals. This IGR is biodegradable and does not accumulate in food chains. It is degraded quickly, especially in water, and has a favorable ecological profile (Niemi 1999; Henrick 2008).

Autodissemination Stations

Pyriproxifen (Sumilarv®) is another IGR with low toxicity to mammals and high toxicity to mosquito larvae (Sumitomo Corporation). Some success has been seen with autodissemination stations. Stations may be as simple as a container lined with cloth containing pyriproxifen. Adult mosquitoes contact pyriproxifen, then passively transfer it to a breeding source, preventing mosquito development and emergence. This approach can be very effective against container breeders such as *Ae. albopictus* (Caputo et al. 2012).



***Culex* sp. pupa** ***Anopheles* sp. pupa**



***Culex* sp. larva**

Pyriproxifen may eventually be applied to catch basins and other areas. For instance, pyriproxyfen (Sumilarv 0.5% G) applied to catch basins in a Southern California park provided 100% inhibition of adult emergence of *Culex quinqefasciatus* for 3 weeks. After 5-8 weeks, larval mortality rates dropped, but pyriproxifen was transferred by emerging mosquitoes into untreated catch basins leading to high mortality there (Faraji and Unlu 2016; Mian et al. 2017).

Surface Films

One of the oldest mosquito control methods is application of oil to the surface of water to suffocate immature mosquitos. Products like Golden Bear Oil, surfactants such as Agnique® and other products are available. Surface films should be used as a last resort because they may have an impact on non-target aquatic wildlife (Contra Costa 2015).

Bat Predators

Several experiments have shown that mosquitoes are about 1% of a bat's diet. These experiments have caused organizations such as the American Mosquito Control Association to conclude that bats are not important mosquito predators (AMCA 2014). However, new research has shown that bats may concentrate their predation on gravid mosquitoes. In an outdoor experiment, researchers counted the number of egg masses laid by mosquitoes inside cages that contained either a caged northern longeared bat, *Myotis septentrionalis*, or no bat. The caged bat reduced the number of mosquito egglaying sites by 32%. Bats may be important predators of West Nile mosquitoes such as *Culex* that bite and lay eggs at night (Reiskind and Wund 2009).

Adult Mosquito Traps

Mosquito traps have been used for more than a century for professional mosquito surveillance. Early models were the CDC and New Jersey light traps and the EVS carbon dioxide trap. These caught small numbers of mosquitoes that were attracted to light or carbon dioxide. Until the late 1990s, the only option for the residential backyard was the zap trap—a light-baited electrocution trap that killed very few mosquitoes and eliminated many beneficial insects (Nasci et al. 1983; Frick and Tallamy 1996). Since then, mosquito traps have been vastly improved. A major advance was traps that use attractants targeted for mosquitoes and biting insects; beneficial insects are spared. Mosquito traps were reviewed in an earlier *Common Sense Pest Control Quarterly* (see Quarles 2003).

Commercially Available Traps

Commercially available mosquito traps use attractants such as heat, light, octenol, and carbon dioxide. Mosquitoes attracted to the traps are captured by fans that pull them either into a net, sticky trap, catch basin or electric grid. The most effective traps use carbon dioxide as an attractant. Either the carbon dioxide is supplied from a cylinder, such as the Mega-Catch® trap, or it is supplied from the catalytic burning of propane, the case of the Mosquito Magnet® trap. Although there are several other kinds of mosquito traps, the Mega-Catch (see Resources) and the Mosquito Magnet (see Resources) often catch more mosquitoes in comparison tests (Kline 2003; Consumer Reports 2003; Kline 2007).

Are They Effective?

Can mosquito traps baited with CO_2 and octenol successfully reduce backyard mosquito populations? Or better yet, can they reduce the number of bites? Mass trapping with attractants and traps has certainly been successful in some cases. USDA scientists D.L. Kline and D.R. Barnard were able to trap an estimated 90% of the pest salt marsh mosquitoes, *Aedes taeniorhynchus*, that plagued a 63-acre (25.5 ha) country club on Key Island at the northern end of the Florida Everglades. Kline and Barnard used mosquito traps baited with cylinders of CO_2 and octenol. They used 52 traps set about 20 feet (6 m) apart, and traps were harvested every 30 days. After one intense 30-day period, more than 2 billion mosquitoes were collected—nearly 23 gallons (87 liters) of mosquitoes (Adams 1996; Kline and Lemire 1998).

Commercial Mosquito Magnet traps successfully reduced biting pressure of *Aedes taeniorhynchus* mosquitos on three small islands near Cedar Key, Florida. Moderate suppression of mosquito biting populations were seen in Gainesville and St. Augustine, Florida (Kline 2006). In British Columbia, Mosquito Magnet traps reduced populations of *Aedes strictus* and *Aedes vexans* by about 30% (Jackson et al. 2012). But the traps were ineffective in Panama City Beach, Florida (Smith et al. 2010).

In cases of failure, traps have been overwhelmed by hordes of mosquitoes flying in from a distance. In rural Canada, four Mosquito Magnet Pro traps caught 2,000,000 mosquitoes in 94 days. However, human landing counts and mosquitoes caught in monitoring traps were not significantly different from untreated areas (Henderson et al. 2006).

Trapping may be more successful with mosquitoes such as *Culex nigripalpus* or *Aedes sierrensis* with low dispersal activity. Mosquito traps might be useful for trapping out local populations of container breeders. For instance, in Salt Lake City, Utah backyard biting populations of *Aedes sierrensis* mosquitoes were successfully suppressed (Kline 2006).

Drawing by Diane Kuhn

Mosquito Magnet traps use carbon dioxide and octenol as attractants. Mosquitoes are trapped by electric fans.

Trap Placements

Trap placement is one of the keys to success. If a CO_2 baited trap is placed improperly, it could make mosquito problems worse. Traps should be at least 30-40 feet (9-12 m) away from porches or patios and other human congregation areas. If traps are placed too close, mosquitoes will see hosts and track them visually or thermally. Traps may also attract ticks, another reason to put them at a distance.

Traps should be placed between mosquito breeding areas and areas where people will congregate. Mosquitoes should encounter the trap before they encounter hosts. Traps should be placed upwind from human activities, preferably in shady, open locations. Vegetation interferes with dispersal of trap CO_2. Traps in the shade may catch 3x more mosquitoes than those in shade (Crepeau et al. 2013; ABC 2003).

BioGents Sentinel® Trap

Though traps using attractants such as light, carbon dioxide and octenol may be effective for many mosquito species, they are less effective for mosquitoes such as *Aedes aegypti* that bite in the daytime. For these mosquitoes, the BioGents Sentinel® (BGS) trap was developed. The BGS trap uses the BG lure of ammonia, caproic acid, and lactic acid, attractants associated with humans. BGS may also use octenol and carbon dioxide as additional lures. These traps have proven very effective for monitoring container breeding mosquitoes (Rochlin et al. 2016; Bhalala and Arias 2009).

Because container breeding mosquitoes such as *Aedes aegypti* and *Aedes albopictus* do not fly very far from their breeding source, BGS traps or Mosquito Magnet traps with BG lures seem promising for controlling these mosquitos (Faraji and Unlu 2016). BGS traps are commercially available from BioQuip (see Resources).

Egg Laying Traps

Another way to stop mosquitoes is the use of egg laying traps. An attractant draws gravid mosquitoes to the traps, and the mosquitoes are killed by a sticky surface or by contact with a pesticide residue. These have been used for many years to monitor mosquito populations. Recently, inexpensive commercial versions have been introduced for mosquito control, especially for container breeding species (see Resources). Some experiments have shown that these traps can reduce *Aedes aegypti* populations by 60-79% (Barrera et al. 2014a; Barrera et al. 2014b). Both mosquito populations and mosquitoborne infection rates are reduced (Lorenzi et al. 2016). The traps work equally well with either pesticides or sticky surfaces as the lethal agent (Heringer et al. 2016).

Adult Baits

The best way to control mosquitoes is to stop them in the egg and larval stages. Once they become adults, less-toxic choices are fewer. Some experiments have shown success with sugar baits. Both male and female adult mosquitoes are naturally attracted to plant sugars. Low toxicity materials such as boric acid, garlic, and oil of cloves can be added to sugar water to make a bait. Mortality was 91% with garlic oil baits (Qualls et al. 2014; Qualls et al. 2016; Ali et al. 2006). Laboratory experiments show that 0.1% boric acid in 10% sucrose aqueous baits reduced survival, biting, and reproductive rates in *Stegomyia albopicta* mosquitoes (Ali et al. 2006).

Outdoor experiments in cages with 1% boric acid in 5% sugar water led to 80-100% mortality of *Aedes albopictus*. The baits significantly reduced landing rates on humans (Xue et al. 2006). Sugar baits can reduce mosquito populations when sprayed onto vegetation. Non-target effects can be reduced by spraying only non-floral vegetation or using bait stations. Adult baits have great potential, but more research is needed on possible non-target effects (Revay et al. 2014; Contra Costa 2015).

Adulticide Sprays

Adulticide sprays contaminate the environment, have a transient effect, and repeated use may lead to insecticide resistance (Quarles 2001). When sprays are applied, mosquitoes tend to disperse, then return 24 hours later. Streetside foggers may not be effective for container breeders in a backyard. Repeated applications of ultralow volume (ULV) insecticides are needed (Farajollahi et al. 2012; Unlu et al. 2015). Barrier sprays of persistent pesticides such as the pyrethroid bifenthrin can have large environmental impacts, and lead to resistance (Cilek et al. 2008). Mosquito adulticides should be used as a last resort, in areas containing large populations of adult mosquitoes known to be carrying disease (Mount et al. 1996; Contra Costa 2015).

Personal Protection

If you are having a party outside, one of the best mosquito deterrents is an oscillating electric fan. Mosquitoes are weak fliers that have difficulty flying upwind. Also, the fan dilutes the carbon dioxide being exhaled by your guests, making it harder for mosquitoes to find you (Hoffmann and Miller 2003). Burning candles can give some protection. Geraniol candles are more effective than those containing citronella. Protection is a function of distance, at 3 feet (1 m) repellency is about 81.5%, at 9 feet (3 m), repellency is about 49.5% (Muller et al. 2008ab).

Photo courtesy Springstar Inc.

The Springstar egglaying trap catches gravid mosquitoes without using pesticides.

Mosquitoes lurk on backyard vegetation before seeking a bloodmeal. These populations can be reduced through trimming vegetation or applying sprays of garlic oil (Mosquito Barrier®) (see Resources)(Unlu et al 2015). Garlic oil is a mosquito repellent (Snow and Cutler 2006), and is lethal if mosquitoes ingest it (Qualls et al. 2016).

If you have to sleep in an area full of mosquitoes, the best solution is mosquito netting. Outside in a high density mosquito environment, bee veil type netting can give protection for your face. Long sleeved sweatshirts can reduce bites. Permethrin treated coveralls such as those used for ticks (see second article) might be useful for an overwhelming mosquito deluge (Olkowski 2001).

The best protection against mosquitoes inside your house is exclusion. Make sure that windows and doors fit tightly. Window screens should be in good repair. Screen doors provide another layer of protection (Olkowski 2001).

Repellents

There are two kinds of mosquito repellents: spatial repellents and personal repellents. Spatial repellents such as mosquito coils and diffusers can be effective for repelling mosquitoes. Mosquito coils are formulations of incense infused with insecticide. Burning the incense releases smoky pesticides into the air, repelling mosquitoes. However, health effects of inhaling these products have not been well researched (Contra Costa 2015). Active ingredients of the diffusers can be essential oils (Mosquito Cognito®) or pesticides (ThermaCell®; Off Clip On®) (see Resources). These can be effective in repelling mosquitoes in a limited area around the device. However, you will be constantly exposed either to pesticides or essential oils (Quarles 2003; Collier et al. 2006; Revay et al. 2013ab).

There are a large number of commercially available personal mosquito repellents, many of them from botanical sources (Quarles 1996; Quarles 2009). According to the CDC, the best of these for disease protection are deet, picaridin, and oil of lemon eucaplytus (see Resources). The CDC bases its assessment on both effectiveness and persistence (CDC 2017c). Personal repellents should be the protection method of choice, especially in areas known to have disease carrying mosquitoes.

Conclusion

The first step in mosquito control is source reduction. All possible breeding sites around your house should be eliminated. All containers of water should be emptied or covered with mosquito screens. Ornamental ponds and treeholes can be treated with BTI briquets. Ponds can also be stocked with mosquito fish. Make sure that your mosquito abatement district is pursuing an aggressive larval control program. Mosquito adult and egglaying traps may help in some situations. Trimming vegetation or treatment with Mosquito Barrier may reduce hiding places. For backyard protection, electric fans or geraniol candles can provide protection. Your home should be tightly screened against mosquitoes. When venturing outside, personal repellents should be used, especially when disease carrying mosquitoes are in your neighborhood. With reasonable caution, we should all be free of mosquito-borne diseases.

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References

ABC (American Biophysics Corporation). 2003. Placement of traps. www.mosquitomagnet.com.

Adams, S. 1996. A high-tech mosquito barrier. *Agricultural Research* 44(3):12-14.

Alameda. 1999. Mosquito Control Program of the Alameda County Mosquito Abatement District. Alameda County Mosquito Abatement District, 23187 Connecticut St., Hayward, CA 94545. 62 pp.

Ali, A., R.D. Xue and D.R. Barnard. 2006. Sublethal exposure to boric acid sugar bait on survival, host-seeking, bloodfeeding behavior, and reproduction of *Stegomyia albopicta*. *J. Am. Mosq. Control Assoc.* 22(3):464-468.

AMCA (American Mosquito Control Association). 2014. Frequently asked questions. www.mosquito.org/faq

Barrera, R., M. Amador, V. Acevedo et al. 2014a. Sustained, areawide control of *Aedes aegypti* using autocidal gravid ovitraps. *Am. J. Trop. Med. Hyg.* 91(6):1269-1276.

Barrera, R., M. Amador, V. Acevedo et al. 2014b. use of the CDC autocidal gravid ovitrap to control and prevent outbreaks of *Aedes aegypti* (Diptera: Culicidae). *J. Med. Entomol.* 51(1):145-154.

Bhalala, H. and J.R. Arias. 2009. The Zumba mosquito trap and BG-Sentinel trap: novel surveillance tools for host seeking mosquitoes. *J. Am. Mosq. Control Assoc.* 25(2):134-139.

Boxmeyer, C.E., S. Leach and S.M. Palchick. 1997. Degradation of Altosid SR Briquets under field conditions in Minnesota. *J. Am. Mosq. Control Assoc.* 13(3):275-277.

Caputo, B., A. Lenco, D. Cianci et al. 2012. The auto-dissemination approach: a novel concept to fight *Aedes albopictus* in urban areas. *PLoS. Negl. Trop. Dis.* 6(8):e1793.

CDC (Centers for Disease Control). 2017a.Mosquito-borne diseases. https://www.cdc.gov/niosh/topics/outdoor

CDC (Centers for Disease Control). 2017b. 2016 Zika Case Counts in the U.S. https://www.cdc.gov/zika/reporting

CDC (Centers for Disease Control). 2017c. Protect yourself and your family from mosquito bites, use insect repellent. https://www.cdc.gov/zika/prevention

Chan, J.F.W., G.K.Y. Choi, C.C.Y. Yip et al. 2016. Zika fever and congenital Zika syndrome: an unexpected emerging arboviral disease. *J. Infect.* 507-524.

Cilek, J.E. 2008. Application of insecticides to vegetation as barriers against host-seeking mosquitoes. *J. Am. Mosq. Control Assoc.* 24(1):172-176.

Collier B.W., M.J. Perick, G.Q. Boquin et al. 2006. Field evaluations of mosquito control devices in southern Louisiana. *J. Am. Mosq. Control Assoc.* 22:444-450.

Consumer Reports. 2003. Should you trap or zap? *Consumer Reports* May:16-17.

Contra Costa. 2015. *Alternatives Analysis Report.* Contra Costa County, Integrated Mosquito and Vector Management Program, 155 Mason Circle, Concord, CA 94520. 140 pp.

Crepeau, T.N. et al. 2013. Effects of Biogents Sentinel trap field placement on capture rates of adult Asian tiger mosquitoes, *Aedes albopictus*. *PLoS ONE* 8(3):e60524, March 29, 2013.

Resources

Bacillus sphaericus (VectoLex®)—Valent BioSciences, 870 Technology Way, Libertyville, IL 60048, 800-323-9597

Bacillus thuringiensis israelensis (BTI) (Teknar®, Vectobac®)—Valent BioSciences, see above

BioGents Sentinel® (trap)—BioQuip Products, 2321 Gladwick St., Rancho Dominguez, CA 90220, 310-667-8800, www.bioquip.com

Lemon Eucalyptus Repellent (Repel®)—WPC Brands, 1 Repel Rd., Jackson, WI 53037, 800-558-6614, www.repel.com

MegaCatch® (trap)—EnviroSafe, PO Box 81101, When Ua Pai 0618, Aukland, New Zealand, www.megcatch.com

Methoprene IGR (Altosid®)—Central Life Sciences, 1501 E. Woodfield Road, Suite 200 West, Schaumberg, IL 60173; 800-248-7763; Harmony Farm Supply, 3244 Gravenstein Hwy, Sebastopol, CA 95472; 707-823-9125

Mosquito Barrier® (garlic)—Garlic Research Labs, 624 Ruberta Avenue, Glendale, CA 91201, 800-424-7990

Mosquito Cognito® (diffuser)—BioSensory, Belding Mill Complex, 107 Providence St. Putnum, CT 06260, 860-928-1113

Mosquito Dunks® (BTI)—Summit Chemical Company, 235 S. Kresson St., Baltimore, MD 21224, 800-227-8664; Harmony Farm Supply, see above

Mosquito Magnet® (trap)—Woodstream, 69 N. Locust St., Lititz, PA 17543, 800-800-1819

Off Clip On® (diffuser)—SC Johnson, 1525 Howe St., Racine, WI 53403, 800-494-4855, www.scjohnson.com

ThermaCell® (diffuser)—ThermaCell, 866-753-3837

Trap-N-Kill® (egglaying trap)—Springstar, PO Box 2622, Woodinville, WA 98072, 800-769-1043, www.springstar.net

Epstein, P. 2000. Is global warming harmful to health? *Sci. Amer.* August: 50-57.

Epstein, P. 2005.Climate change and human health. *N. Engl. J. Med.* 353(14):1433-1436.

Epstein, P. 2007. Chikungunya fever resurgence and global warming. *Am. J. Trop. Med. Hyg.* 76(3):403-404.

Faraji, A. and I. Unlu. 2016. The eye of the tiger, the thrill of the fight: effective larval and adult control measures against the Asian tiger mosquito, *Aedes albopictus* (Diptera: Culicidae) in North America. *J. Med Entomol.* 53(5):1029-1047.

Farajollahi, A., S.P. Healy, I. Unlu et al. 2012. Effectiveness of ultra-low volume nighttime applications of an adulticide against diurnal *Aedes albopictus*, a critical vector of dengue and chikungunya viruses. *PLoS ONE* 7:e49181.

Federici, B.A. 1995. The future of microbial insecticides as vector control agents. *J. Am. Mosq. Control Assoc.* 11(2):260-268.

Frick, T.B and D.W. Tallamy. 1996. Density and diversity of nontarget insects killed by suburban electric insect traps. *Entomological News* 107(2):77-82.

Hahn, M.B., R.J. Eisen, L. Eisen et al. 2016. Reported distribution of *Aedes aegypti* and *Aedes albopictus* in the United States 1995-2016. J. *Med. Entomol.* 53(5):1169-1175.

Henderson, J.P., R. Westwood and T. Galloway. 2006. An assessment of the effectiveness of the mosquito magnet Pro model for suppression of nuisance mosquitoes. *J. Am. Mosq. Control Assoc.* 22(3):401-407.

Henrick, C.A. 2008. Methoprene. *J. Am. Mosq. Control Assoc.* 23(sp2):225-239.

Heringer, L., B.J. Johnson, K. Fikrig et al. 2016. Evaluation of alternative killing agents for *Aedes aegypti* in the gravid Aedes trap (GAT). *J. Med. Entomol.* 53(4):873-879.

Hoffmann, E.J. and J.R. Miller. 2003. Reassessment of the rote and utility of wind in suppression of mosquito host finding: stimulus dilution supported over flight limitation. *J. Med. Entomol.* 40(5):607-614.

Jackson, M.J., J.L. Gow, M.J. Evelyn et al. 2012. An evaluation of the effectiveness of a commercial mechanical trap to reduce abundance of adult nuisance mosquito populations. *J. Am. Mosq. Control Assoc.* 28:292-300.

Kline, D.L. and G.F. Lemire. 1998. Evaluation of attractant-baited traps/targets for mosquito management on Key Island, Florida, USA. *J. Vector Ecol.* 23(2):171-185.

Kline, D.L. 2003. Large cage and field comparison tests of MegaCatch and Mosquito Magnet traps. USDA Report, 1600 SW 23rd Dr., Gainesville, FL 32608. 6pp.

Kline, D. 2006. Traps and trapping techniques for adult mosquito control. *J. Am. Mosq. Assoc* 22(3):490-496.

Kline, D. 2007. Semiochemicals, traps/targets and mass trapping technology for mosquito management. *J. Am. Mosq. Control Assoc.* 23(sp2):241-251.

Kraemer, M.U.G., M.E. Sinka, K.A. Duda et al. 2015. The global distribution of the arbovirus vectors *Aedes aegypti* and *Ae. albopictus. eLife* 4:e08347.

Lacey, L.A. 2007. *Bacillus thuringiensis* servariety *israelensis* and *Bacillus sphaericus* for mosquito control. *J. Am. Mosq. Control Assoc.* 23(sp2):133-163.

Levy, R., C.N. Powell, B.C. Hertlein and T.W. Miller, Jr. 1984. *Mosquito News* 44(4):537-543.

Lorenzi, M.S., C. Major, V. Acevdo et al. 2016. Reduced incidence of chikungunya virus infection in communities using *Aedes aegypti* mosquito trap intervention studies. *MMWR* 65 (18):479-480.

Metzger, M.E., M.H. Yoshiizu, K.A. Padgett et al. 2017. Detection and establishment of *Aedes aegypti* and *Aedes albopictus* mosquitoes in California, 2011-2105. *J. Med. Entomol.* 54(3):533-543.

Mian, L.S., M.S. Dhillon and L. Dodson. 2017. Field evaluation of pyriproxifen against mosquitos in catch basins in Southern California. *J. Am. Mosq. Control Assoc.* 33(2):145-147.

Mount, G.A., T.L. Biery and D.G. Haile. 1996. A review of ultralow volume aerial sprays of insecticide for mosquito control. *J. Am. Mosq. Control Assoc.* 14(3):305-334.

Mulla, M.S. 1995. The future of insect growth regulators in insect control. *J. Am. Mosq. Control Assoc.* 11(2):269-273.

Mulla, M.S., J. Rodcharoen, W. Ngamsuk, A. Tawatsin, P. P.-Urap and U. Thavara. 1997. Field trials with *Bacillus sphaericus* formulations against polluted water mosquitoes in a surburban area of Bangkok, Thailand. *J. Am. Mosq. Control Assoc.* 13(4):297-304.

Muller, G.C., A. Junnila, V.D. Kravchenko et al. 2008a. Indoor protection against mosquito and sand fly bites: a comparison between citronella, linalool, and geraniol candles. *J. Am. Mosq. Control Assoc.* 24(1):150-153.

Muller, G.C., A. Junnila, V.D. Kravchenko et al. 2008b. Ability of essential oil candles to repel biting insects in high and low biting pressure environments. *J. Am. Mosq. Control Assoc.* 24(1):154-160.

Nasci, R.S., C.W. Harris and C.K. Porter. 1983. Failure of an insect electrocuting device to reduce mosquito biting. *Mosquito News* 43(2):180-185.

Niemi, G.J., A.E. Hershey, L. Shannon et al. 1999. Ecological effects of mosquito control on zooplankton, insects and birds. *Environmental Chem. Toxicol.* 18(3):549-559.

Olkowski, W., S. Daar and H. Olkowski. 1991. *Common Sense Pest Control.* Taunton Press, Newtown, CT. 715 pp.

Olkowski, W. 2001. Larval control of mosquitoes. *Common Sense Pest Control Quarterly* 17(2):8-18.

Qualls, W.A., G.C.Muller, E.E. Revay et al. 2014. Evaluation of attractive toxic sugar bait (ATSB)—barrier for control of vector and nuisance mosquitoes and its effect on non-target organisms in subtropical environments in Florida. *Acta Tropica* 121:104-110.

Qualls, W.A., J. Scott-Fiorenzano, G.C. Muller, et al. 2016. Evaluation and adaptation of attractive toxic sugar baits for *Culex tarsalis* and *Culex quinquefasciatus* control in the Coachella Valley, Southern California. *J. Am. Mosq. Control Assoc.* 32(4):292-299.

Quarles, W. 1996. Botanical mosquito repellents. *Common Sense Pest Control Quarterly* 12(4):12-19.

Quarles, W. 2001. Sprays for adult mosquitoes—a failed technology? *Common Sense Pest Control Quarterly* 17(2):3-7.

Quarles, W. 2003. Mosquito attractants and traps. *Common Sense Pest Control Quarterly* 19(2):4-13.

Quarles, W. 2007. Global warming means more pests. *IPM Practitioner* 29(9/10):1-9.

Quarles, W. 2009. Mosquito repellents from the salad bowl. C*ommon Sense Pest Control Quarterly* 25(2-4):3-10.

Quarles, W. 2010. Risks of the natural world. *Common Sense Pest Control Quarterly* 26(1-4):3-6.

Quarles, W. 2016. Zika virus arrives in the U.S. *IPM Practitioner* 35(5/6):10.

Quarles, W. 2017. Global warming means more pathogens. *IPM Practitioner* 35(7/8):1-7.

Reiskind, M.H. and M.A. Wund. 2009. Assessment of the impacts of northern long-eared bats on ovipositing *Culex* (Diptera: Culicidae) mosquitoes. *J. Med. Entomol.* 46(5):1037-1044.

Revay, E.E., A. Junnila, R. Xue et al. 2013a. Evaluation of commercial products for personal protection against mosquitoes. *Acta Tropica* 125:226-230.

Revay, E.E., D.L. Kline, R.D. Xue et al. 2013b. Reduction of mosquito biting pressure: spatial repellents or mosquito traps? *Acta Tropica* 127(1):127(1):63-68.

Revay, E.E., G.C. Muller, W.A. Qualls et al. 2014. Control of *Aedes albopictus* with attractive toxic sugar baits (ATSB) and potential impact on non-target organisms in St. Augustine, FL. *Parasitol. Res.* 113:73-79.

Rochlin, I., M. Kawalkowski and D.V. Ninivaggi. 2016. Comparison of Mosquito Magnet and Biogents Sentinel traps for operational surveillance of container inhabiting *Aedes* (Diptera: Culicidae) species. *J. Med. Entomol.* 53(2):454-459.

Service, M.W. 1980. *A Guide to Medical Entomology*. Macmillan, New York. 226 pp.

Service, M.W. 1993. *Mosquito Ecology Field Sampling Methods*. Elsevier, New York. 988 pp.

Service, M.W. 1995. Can we control mosquitoes without pesticides? A summary. *J. Am. Mosq. Control Assoc.* 11(2):290-293.

Siegel, J.P. and R.J. Novak. 1997. Field trials of VectoLex, *a Bacillus sphaericus* larvicide, in Illinois waste tires and catch basins. *J. Am. Mosq. Control* Assoc. 13(4):305-310.

Smith, J.P., E.H. Cope, J.D. Walsh et al. 2010. Ineffectiveness of mass trapping for mosquito control in St. Andrews State Park, Panama Beach Florida. *J. Am. Mosq. Control Assoc.* 26(1):43-49.

Snow, K. and R. Cutler. 2006. A preliminary note on the evaluation of garlic as a mosquito repellent. *Eur. Mosq. Bull.* 21:23-24.

Swiger, S.L. 2016. Mosquitoes and the diseases they transmit. Pub. Ento-040, Texas A and M Agrilife Extension. 12 pp.

Unlu, I., K. Klingler, N. Indelicato et al. 2015. Suppression of *Aedes albopictus*, the Asian tiger mosquito, using a 'hot spot' approach. *Pest Manag. Sci.* 72:1427-1432.

USGS (United States Geological Survey). 2017. *Gambusia affinis* factsheet. https://nas.er.usgs.gov

Vanlandingham, D.L., S. Higgs and Y.J.S. Huang. 2016. *Aedes albopictus* and mosquito-borne viruses in the United States. *J. Med. Entomol.* 53(5):1024-1028.

Xue, R.D., D.L. Kline, A. Ali et al. 2006. Application of boric acid baits to plant foliage for adult mosquito control. *J. Am. Mosq. Control Assoc.* 22(3):497-500.

Preventing Tickborne Diseases

By William Quarles

Ticks carry pathogens that cause human diseases, and infected ticks are increasing in abundance due to global warming and other factors (Quarles 2017). The most prevalent tickborne disease in the U.S. is Lyme disease. Confirmed Lyme disease cases in the U.S. have doubled in the last 20 years. The EPA has estimated that there are 300,000 new cases of Lyme disease each year (EPA 2016). Confirmed cases in Canada have increased more than 10-fold since 2005 (Kulkarni et al. 2015; Leighton et al. 2012; Brownstein et al. 2005).

Lyme disease is caused by a spirochete called *Borrelia burgdorferi*, that is carried by the tick *Ixodes scapularis* in the East and *Ixodes pacificus* in the West. Spirochetes are corkscrew shaped bacteria that cause a number of diseases including relapsing fever, leptospirosis, syphilis, and others. Lyme disease, like syphilis, can cause longterm chronic problems involving the nervous system. There may be a red bullseye rash, fatigue, fever, headache, stiff neck, encephalitis, heart inflammation, muscle weakness and pain, and arthritis. Symptoms may or may not abate after antibiotic treatment. *B. burgdorferi* shows a lot of genetic variability, and some genotypes may be harder to treat than others (Sonenshine 1993; Burgdorfer 1993; Quarles 2000).

In addition to Lyme disease, at least 18 human pathogens can be transmitted by ticks (Stromdahl and Hickling 2012). For instance, the Lyme disease tick, *Ixodes scapularis*, carries *Borrelia burgdorferi* for Lyme disease; *Anaplasma phagocytophylium* that causes anaplasmosis; *Babesia microti* that causes babesiosis; and Powassen virus that causes Powassen encephalitis (Stromdahl and Hickling 2012). There are often co-infections with mixed Borrelia such as *B. miyamotoi* and *B. burgdorferi*. In the Northeast the human infection rate with *B. burgdorferi* is about twice that of *B. miyamotoi* (Krause et al. 2014). In the San Francisco Bay Area, *I. pacificus* ticks infected with *B. burgdorferi* are about as abundant as those with *B. miyamotoi* (Salkeld et al. 2014).

The major pathogenic tick in the Northeast is *Ixodes scapularis*. The major tick in the Southeast is the lone star tick, *Amblyomma americanum*. The lone star tick, *Amblyomma americanum* carries *Ehrlichia* spp. organisms that cause ehrlichiosis; *Francisella tularensis* that causes tularemia; *Rickettsia rickettsii* that causes spotted fever rickettsiosis; and southern tick associated rash illness (STARI). Bites can cause multiple diseases and immune system problems (Stomdahl and Hickling 2012). Other important ticks are the dog tick, *Dermacentor variabilis*; the Rocky mountain wood tick, *Dermacentor andersoni*; and the brown dog tick, *Rhipicephalus sanguineus*. Tick descriptions are given in Stafford (2004).

Photo courtesy Scott Bauer USDA

The blacklegged tick, *Ixodes scapularis*, carries pathogens for several diseases, including Lyme disease.

This article outlines strategies that allow us to enjoy natural surroundings while preventing tick bites and tickborne diseases. Since Lyme disease is the greatest risk from a tick bite, we will concentrate on Lyme disease.

Importance of Ecology

The Lyme disease ticks, *I. scapularis* and *I. pacificus*, have a 2-year reproductive cycle. Life stages are eggs, larvae, nymphs and adults. A female adult *I. scapularis* lays about 2500 eggs in June of year one. Eggs hatch into larvae that attach to hosts such as small mammals and birds. If the host is infected, the pathogen is transmitted to tick larvae. Infected larvae molt into infected nymphs that bite humans and other mammals the following spring, spreading the pathogen and causing disease. Nymphs then molt into adults that overwinter and lay eggs in June at the end of year two (Bosler 1993).

For epidemic spread of the disease, there must be infected ticks (vector), an animal capable of sustaining the infection (reservoir), and animals on which adult ticks can mate and be carried to new locations (amplifier) (Spielman et al. 1985). The blacklegged tick, *I. scapularis*, transmits Lyme disease to humans in the Northeast, where most of the cases occur. *I. scapularis* will feed on at least 31 different mammals and 49 species of birds, so there are numerous possibilities for spreading the infection (Anderson 1988).

Larval *I. scapularis* pick up the infection by feeding on hosts that live near the ground. In the Northeast, the reservoir is the white-footed mouse, *Peromyscus leucopus*, because these rodents are numerous and easy to infect. As many as two-thirds of these animals may be infected,


Drawing by Diane Kuhn

The white-footed mouse, *Peromyscus leucopus*, infects larval ticks with the Lyme disease pathogen.

and up to 90% of the immature ticks feed on these mice. One mouse can simultaneously infect up to 400 feeding ticks. The mice help sustain the ticks, as increasing mouse density in an area is associated with increased tick density (Spielman et al. 1985; Levin and Fish 1998). When white-footed mice are not available, meadow voles, *Microtus pennsylvanicus*, take their place as a pathogen reservoir (Markowski et al. 1998). Birds may also be secondary hosts and reservoirs in the northeast (Battaly and Fish 1993).

Other mammals such as opossums and squirrels may actually reduce the number of infected ticks by dedicated grooming. One opossum may kill more than 5,000 ticks a year (Keesing et al. 2009). Adult ticks are spread by deer. Deer are not competent reservoirs for the pathogen, but they carry mating adult ticks into new areas (Telford et al. 1988). Ticks then drop off and lay eggs. It is very important to exclude deer from your property.

Preventing Lyme Disease

Lyme disease can be prevented by a program of tick avoidance, personal prevention, and an IPM program to prevent the spread of infected ticks. Greatest risks for Lyme disease are in New York, Connecticut and other northeastern states. If you visit high risk areas, use personal protection as described below. The risk of Lyme disease is greatest in or near forested areas where there are abundant ticks, deer, and mice. When houses are built adjacent to forested areas, then areas around these houses are at risk (Sonenshine 1993).

Tick Bites at Home

Falco and Fish (1988) found that nearly 70% of *I. scapularis* tick bites in the Northeast happened after backyard exposures. Stafford (2004) estimated that about 75% of Lyme disease cases in the Northeast result from bites on residential property (Eisen and Eisen 2016). Nymphal ticks tend to be found in leaf litter, adults can be found on tall grassy vegetation. The good news is that ticks cannot fly or jump, they must make direct contact with a host. There is a moderate risk in ornamental planting beds; risks are minimal on mowed lawns (Sonenshine 1993; Barbour 1996; Stafford 2004).

Habitat Management

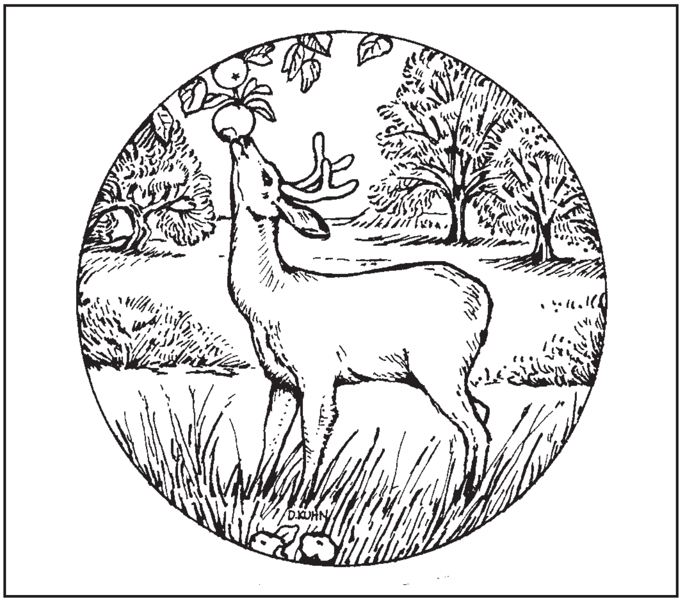
You can reduce exposure to ticks near your home with vegetation management. Increase the amount of sunshine on the ground by pruning trees. Lyme disease ticks do not like low humidity and dry conditions (Vail and Smith 1998). Nymphal ticks are more sensitive to dehydration than adults. Under dry conditions, more of them stay close to the ground and feed on small hosts such as mice instead of humans. Larvae go quiescent in dry conditions, and only bite as the humidity increases (Randolph and Storey 1999).

Keep watering to a minimum. Keep grasses along paths and roadside mowed to ankle height. Ticks then have fewer grass attachment sites. Cut grass, weeds, and brush along footpaths, roads and fields where ticks are a problem. Repeated mowing in one area resulted in a 70% reduction of ticks (Schulze et al. 1988).

Controlled burns of vegetation for tick control have little value. Immediately after burning, there are very few ticks, but after a couple of months populations recover to the same level as before. Also controlled burns might be dangerous near houses (Stafford et al. 1998).

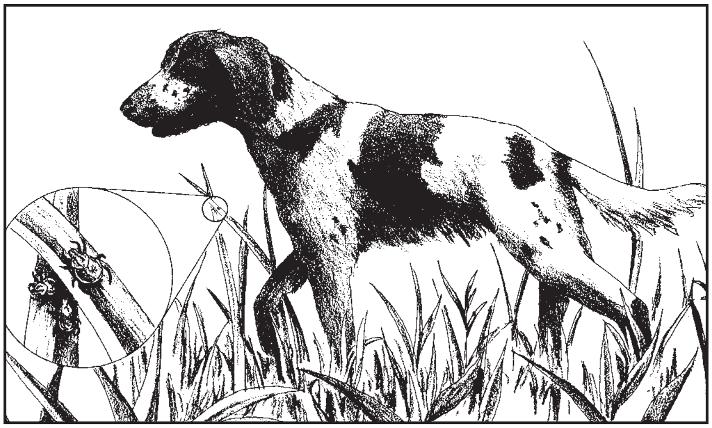
Discourage rodents and small mammals by removing vegetation that encourages them. Small rodents eat grass seeds and hide from predators in weeds and vines. Brushy habitat provides cover for raccoons, skunks, foxes, and opossum. Deer need browse, and can be discouraged if there is no food (Olkowski et al. 1990).

Remove trash and brush piles, stack firewood away from the house, remove piles of stones and debris that can harbor mice. Rake up leaves and compost them. In New York, clearing leaf litter reduced ticks by 48-87%, and wood chip mulch barriers reduced ticks by 42-64%



Drawing by Diane Kuhn

Deer carry ticks and should be excluded.



Ticks lurk on tall grass, waiting for a host. Prevent ticks by mowing grass.

(Piesman 1999; 2006). Move bird feeders away from dwellings to discourage rodents. Exclude deer with deer fencing. Although deer exclusion from your property makes sense, areawide deer destruction does not. Destruction of about 70% of the deer population in one area had little effect on tick abundance (Spielman 1988).

Tick Bites in Recreation Areas

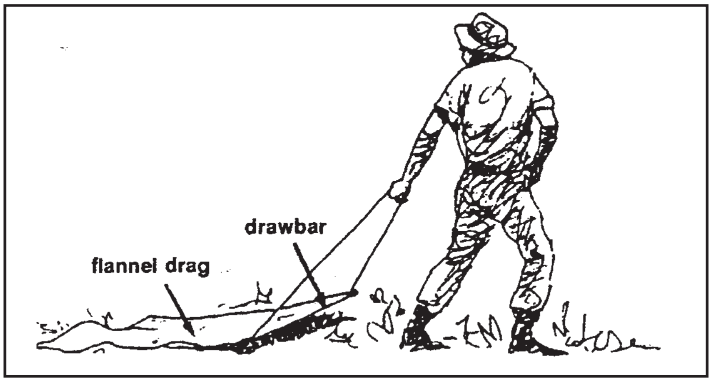
A common theme of Lyme disease ticks is water and forests. Thus they are found along the coasts, along rivers, around lakes and other water bodies (Dennis et al. 1998). In areas other than New England, the risk of a tick bite and subsequent disease is usually greater in wooded recreational areas than at home. Risks depend on the tick density, tick infection rate, and frequency of contact. The Lyme disease tick infection rate in New England is about 10-36%. Risks are lower in California where the infection rate of *I. pacificus* is 1-5%. The infection rate is lower in California because blood of the western fence lizard host contains antibiotics. Ticks and infections tend to cluster, and infection rates in some areas could be 10x that of another similar area (Lane and Lavoie 1988; Lane and Quistad 1998; Barbour 1996; Stafford 2004).

Risks increase in early morning and late afternoon, as ticks do not like to attach in the heat of the day. Risks are higher in southern exposures and on the uphill side of hiking trails. Leaf litter is a hazard, because these areas can be inhabited by infected nymphs. Sitting on logs in infested areas carries a high risk. Larger numbers of ticks accumulate in ecotones, the ecological areas of interface between grasslands and brush (Kramer and Beesley 1993; Lane 2000; Carroll and Kramer 2001).

If possible, stay clear of narrow hiking trails where you cannot avoid brushing against the vegetation. If you have to use such a trail, keep inspecting hourly for ticks. Avoid brush or trash piles that are likely harboring rodents. Clear areas where you are going to camp or play with a tick drag. [*A tick drag is a piece of cotton flannel cut to a convenient size [eg. 4 ft by 6 ft] for dragging over a tick infested landscape. Questing ticks grab the flannel. Ticks can be removed and killed in a soap solution.*] A tick drag can momentarily reduce tick numbers. Do not sit on the ground unless you have first reduced ticks with a tick drag (Olkowski et al. 1990; Talleklint-Eisen and Lane 2000).

Personal Protection

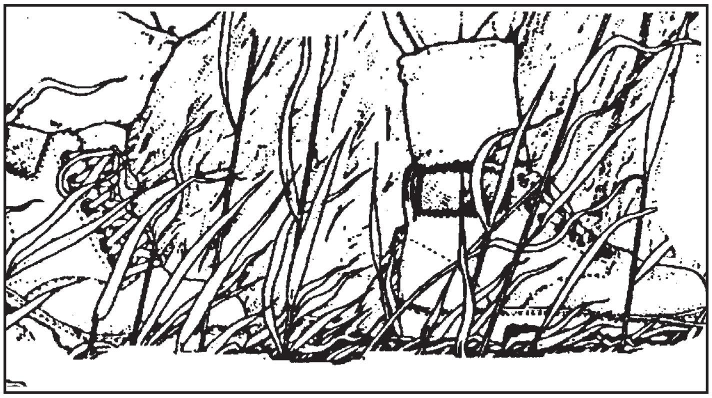
If exposure is intermittent, as on field trips or camping trips, one of the best personal protections is white overalls or a white jump suit or similar clothing that has been treated with with the pyrethroid insecticide permethrin. Field studies have shown that permethrin treated clothing reduces the number of tick bites (see Resources) (Miller et al. 2011). Spraying the garment from the waist down will probably be sufficient. To reduce pesticide exposure, clothing can be sprayed outside the house, using care not inhale the aerosol (Lane 1989).



Drawing courtesy Paul Catts

A tick drag is a good way to monitor ticks and remove them from the environment.

Treatment of clothing with a tick repellent is another option, but repellents are less effective than permethrin. The advantage of personal repellents is that they can be used on skin. One field study showed that lemon eucalyptus extract (Repel™) reduced the number of attached ticks by 62% (see Resources) (Gardulf et al. 2004).



Tuck pant legs into socks to exclude ticks.

If you do not want to have anything to do with pesticides or repellents, wear light-colored clothing and tuck pants into socks. It may be easier to tape pants tight to the leg, then put on socks. In infested areas, check hourly for ticks on the clothing. Most ticks are found crawling between the ankle and the knee. Remove ticks and drop into a plastic pill bottle or film cannister. If friends are hiking with you, have them inspect your neck and head for ticks on an hourly basis in high risk areas (Olkowski et al. 1990; Lane 2000).

When you return home from camping, wash clothing and disinfest gear. Clothes drier temperatures will kill the ticks. Check your entire body at night before you go to bed. Have someone else inspect parts of your body hidden from view, or use a mirror. Pay special attention to the groin, back, armpits and head (Olkowski et al. 1990).

How Quick the Tick

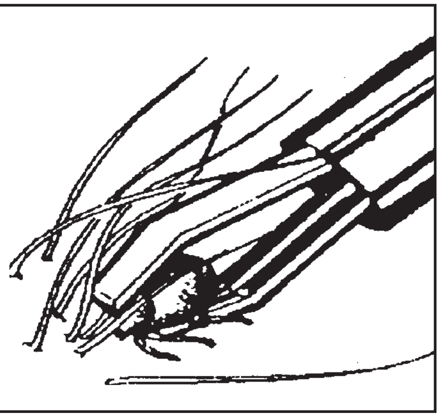
Ticks should be removed as soon as they are found. It takes 24-48 hours for attached *I. pacificus* nymphs to transmit infection to the deer mouse, which is not a preferred host. Transfer from *I. scapularis* ticks to the white-footed mouse is a little more efficient, but the times are about the same. The infection is transferred faster by adult ticks. Humans have been infected within 8 hours of adult *I. pacificus* attachment. The pathogen is systemic in adult ticks and is easily transferred from the salivary glands. The pathogen is transferred from the gut of feeding nymphs (Peavey and Lane 1995; Piesman et al. 1987).

Remove the Tick

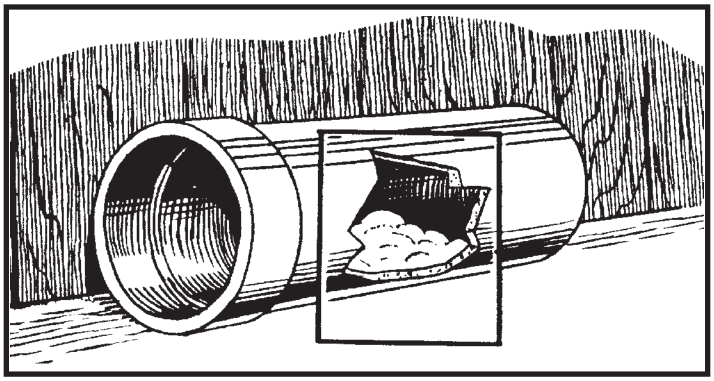
Look closely for attached ticks and remove them. The nymphal *I. scapularis* or *I. pacificus* may be as small as the period at the end of this sentence. Engorged nymphs are the size of a poppy seed. Adults are larger. The best way to remove a tick is with a pair of tweezers (see Resources). Grasp the tick by its embedded head with the tweezers and apply gentle pressure to try to make the tick release. Pull straight out from the skin; do not twist as you pull. Tick mouthparts are like harpoons; they do not screw into the skin. Gentle, steady pulling is the recommended procedure. If you do not have tweezers, use your gloved hands or protect your hands with a tissue. It is very important to remove the tick (Olkowski et al. 1990; Piesman and Dolan 2002).

Do not kill the tick while it is embedded, because this can lead to an infection. Thus, applying a lighted cigarette or a hot needle, putting alcohol, gasoline or kerosene on the tick and lighting it are not recommended. Sometimes applying vaseline to the tick will make it withdraw, but if this does not work, the tweezer method will be more difficult. Also, the longer the tick is attached, the greater the risk of disease. Do not crush the tick, as the pathogens can enter through the punctured skin (Barbour 1996; Olkowski et al. 1990).

Remove a tick with gentle, slow pressure. Pull straight out with tweezers. Do not twist.



After the tick is removed, drop it into alcohol to kill it and preserve it, or crush it with tweezers. Tick identification might be useful in case there is a problem with clinical diagnosis later. The site of the tick bite should be cleaned with alcohol, and an antibiotic applied. Over the counter antibiotic salves will not kill the Lyme disease pathogen, but they will prevent local skin infections from occurring (Barbour 1996).



Rodent shelters treated with permethrin kill ticks.

Use of Pesticides

Rather than killing deer or mice, it is much better to have them work for you on tick elimination. One way is to make sure that nesting rodents are exposed to pesticides. Nesting tubes of plastic pipe lined with permethrin-coated carpet reduced *Ixodes* spp. ticks on woodrats by 99% in Colorado. Field tests have shown that fipronil gives similar results (Piesman 1999). Bait boxes using this concept are commercially available (see Resources). Use of these bait boxes in New Jersey reduced nymphal and larval ticks by 88-97% (Schulze et al. 2017).

Dispersal of tubes containing permethrin-treated cotton (Damminix™) in Connecticut reduced ticks on mice by about 70%. Mice pick up the insecticide-treated cotton and use it as a nesting material. The best time to deploy is late spring and summer (Schulze et al. 1988). These tick tubes are commercially available (see Resources). Distribution of permethrin-treated nesting material (Damminix) for the white-footed mouse led to a 97% reduction in infected ticks in one experiment (Mather et al. 1988).

Bait Stations for Deer

Deer can be treated by an innovative bait station called the “four poster.” [U.S. Patent No. 5,367,983 on Nov. 29, 1994] A central bin of corn is surrounded by feeding stations. As deer feed, the edge of a metal plate above each feeding post forces contact of head, neck and ears with pesticide-coated vertical rollers. Deer rub up against pesticide treated carpet to remove their ticks. An initial field trial with amitraz (Mitac) led to 97% tick removal from deer (Stafford 1998). Subsequent field tests by several researchers confirmed the effectiveness, leading typically to a 46-80% areawide reduction of nymphal *I. scapularis* (Stafford et al. 2009; Carroll et al. 2009; Schulze et al. 2009). Use of the device in an area also reduces the incidence of Lyme disease rash in humans found in that area (Garnett et al. 2011).

Pesticide Sprays

Acaricide sprays will initially clear an area of ticks, but the ticks come back, and sprays must be used again. Sprays are most effective for questing adults since they are more likely to be found at the top of weeds and brush where sprays accumulate. Hence, spraying is best in fall and spring when adult forms are active (Schulze et al. 1988). Sprays of pyrethrins and silica gel (Drione) and insecticidal soap plus pyrethrins have been effective (see Resources) (Stafford 1998; Piesman 1999).

Rather than spray whole areas, ticks may be located by using a tick drag, and sprays can be targeted (Olkowski et al. 1990). The tick drag is generally a good monitoring method, but it can underestimate tick populations if there is a high host density. Then many of the ticks are no longer on vegetation, they are on hosts (Ginsberg and Zhioua 1999).

Botanical Sprays

A number of botanicals can be useful in tick management. The compound noonkatone from cedar oil is one of the most effective. *Ixodes scapularis* nymphal tick reductions of about 96% for 42 days were seen in New Jersey. However, commercial development has been slow (Dolan et al. 2009; Jordan et al. 2011).

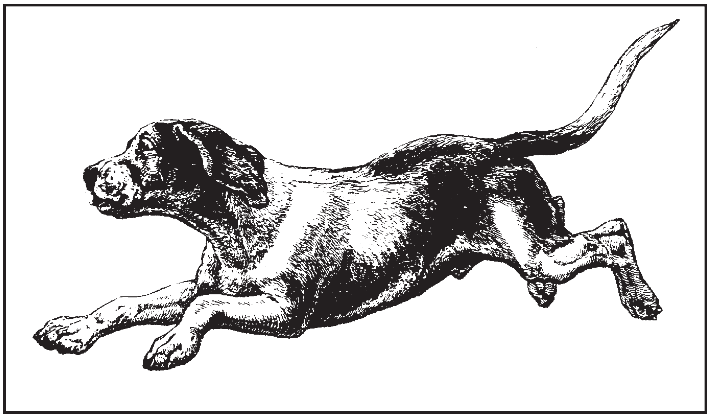
Application of the commercial essential oil formulation IC2 to oak pine forests in Maine was just as effective as maximum label applications of bifenthrin for control of blacklegged tick, *I. scapularis*. Tick populations were controlled for 6-9 months by the essential oil (see Resources). Bees were not affected, but some non-target insects showed decline for about 3 weeks. Bifenthrin protection lasted 12-16 months and had more of an impact on non-target populations (Elias et al. 2013; Rand et al. 2010).

Garlic has also been used with moderate success to control ticks. Application of Mosquito Barrier (0.2 g AI/m^2) to residential properties in Connecticut led to about 50% suppression of nymphal *I. scapularis* ticks for about two weeks (see Resources) (Bharadwaj et al. 2015).

Effectiveness of Residential Sprays

As mentioned earlier, about 75% of Lyme disease cases in New England result from tick bites at home. To reduce the risk, an IPM approach is needed, pesticide sprays alone may not be enough. In one large scale study involving 2727 properties and about 10,000 people over a two year period, the pyrethroid bifenthrin was applied as a perimeter treatment in wooded property, ranging 10 feet into turf and 20 feet into the woods. Ticks were reduced by an average of about 63%. Despite the reduction, 17.1% of those surveyed found an attached tick, and 3% of the people on the treated properties contracted a tickborne disease. Residents of untreated properties also had a 3% infection rate (Hinckley et al. 2016).

Treatment of Pets



In high risk areas, dogs should be inspected regularly for ticks or treated with acaricides.

Dogs and cats can also contract Lyme disease. They can pick up ticks and unattached ticks may drop off inside the house. If you are patient, you can find ticks on your pets by using a flea comb. Unattached ticks are removed with the comb or your fingers and dropped into soapy water. Attached ticks are removed with tweezers. If you are not chemically sensitive, you may be able to use spot-on formulations of fipronil (Frontline™) or imidacloprid + permethrin (Advantix™) on your dog to prevent tick attachment (see Resources) (Jacobson et al. 2004). There are also other new tick control products. Some of them, such as fluralaner (Bravecto™) or afoxolaner (Nexgard™) are given orally to the pet (Burgio et al. 2016). Both spot-ons and oral medications can have adverse reactions. A balance should be struck between the risks of a tick bite, and the risk of an adverse pesticide reaction (EPA 2010).

Biological Control

The chalcid wasp *Ixodiphagus hookeri* is a parasitoid of ixodid ticks including the blacklegged tick, *I. scapularis*. The parasitoid occurs in several states including Texas, Colorado, California, Idaho, Oregon, Florida, Montana, Massachusetts, Rhode Island, New York and Connecticut. The parasitoid develops only in nymphal ticks (Hu and Hyland 1998). But the parasitoid by itself does not effectively control the ticks in the field.

Although *Bacillus thuringiensis kurstaki* (BT) has been shown to kill larval ticks in the laboratory, engorged *I. scapularis* were dipped into solutions containing more than 10 million spores per milliliter. How effective BT would be in the field is so far a matter of speculation (Zhioua et al. 1999a). The nematodes *Steinernema carpocapsae* are effective only against engorged female ticks. In the U.S. *Verticillium* spp. fungi are found most often in captured ticks (Zhioua et al. 1999b).

The fungus *Metarhizium anisopliae* is pathogenic to all stages of the ticks and has much potential as a biocontrol agent (see Resources). Field tests on 100 m^2 plots averaging 10 ticks per plot showed *M. anisopliae* killed about 53% of the ticks (Benjamin et al. 2002; Quarles 2003). Application of *M. anisopliae* when nymphal ticks were active led to an 87-96% reduction, but populations bounced back, and after 5 weeks reduction was 53-74% (Bharadway and Stafford 2010). Other field tests showed about a 56% tick reduction on lawns treated with *M. anisopliae* or *Beauveria bassiana* (Stafford and Allan 2010).

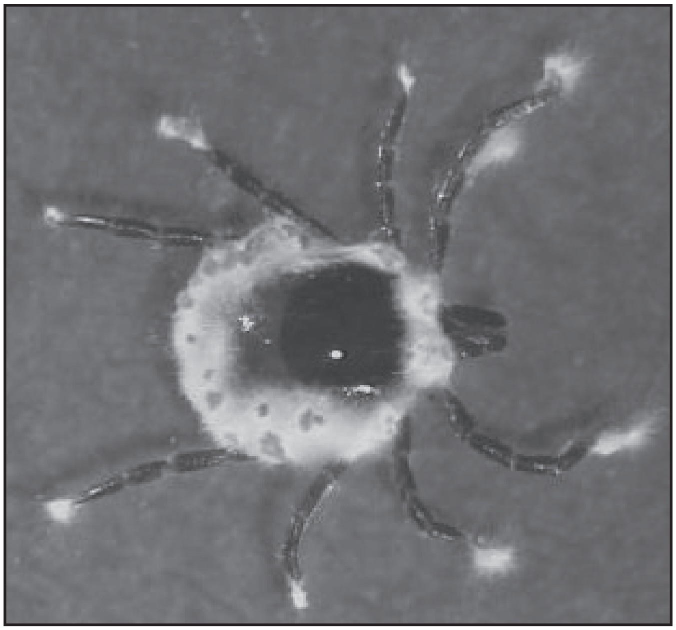


Photo courtesy Charlotte Nelson RVAU Denmark

The commercially available fungus, *Metarhizium anisopliae*, will infect and kill ticks.

Conclusion

Lyme disease can be managed by controlling the key ecological elements responsible for its spread. The tick life cycle can be broken in the larval and nymphal stage with pesticide treatment stations and tick tubes for rodents. Deer should be excluded from your property. Bait stations for deer can kill adult ticks and subsequently reduce nymph populations. An IPM program including vegetation management could be useful close to home. A venture into a high risk area should be accompanied by vigilance and personal protection. Repellents and permethrin treated clothing should be considered. Dogs in high risk areas should be protected with a least-toxic acaricide or with regular tick inspections. Make tick inspection an integral part of camping and hikes. Disinfest camping gear after each trip, and before storage. Unattached ticks can go for months without a host. Remove all attached ticks promptly. Rashes and fever may indicate a tick bite. If you live in a high risk area and a rash should appear, or if you have any of the clinical signs of Lyme or other tick disease seek medical help immediately.

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Resources

Essential Oil Spray (Essentria®)—Central Life Sciences, 1501 E. Woodfield Road, Suite 200 West, Schaumberg, IL 60173, 800-248-7763, www.zoecon.com

Fipronil Spot-On (Frontline®)—Merial, see veterinarian

Garlic Spray (Mosquito Barrier®)—Garlic Research Labs, 624 Ruberta Avenue, Glendale, CA 91201, 800-424-7990, www.garlicbarrier.com

Insecticidal Soap with pyrethrins (Safer®)—Woodstream, 69 N. Locust St., Lititz, PA 17543, 800-800-1819, www.woodstreampro.com

Lemon Eucalyptus Repellent (Repel®)—WPC Brands, 1 Repel Rd., Jackson, WI 53037, 800-558-6614, www.repel.com

Metarhizium anisopliae (MET52®)—Novozymes, 77 Perry Chapel Church Road, Franklinton, NC 27525, 919-494-3000, www.novozymes.com

Permethrin Spray for Clothing, Sawyer Products, PO Box 188, Safety Harbor, FL 34695, 727-725-7811, www.sawyer.com

Permethrin Treated Clothing—Insect Shield, 3201 1st Avenue South, Suite 350, Seattle, WA 98104, 888-884-5784

Permethrin, Imidacloprid Spot-On (Advantix®)—Bayer Corporation, see veterinarian

Tick Bait Box (Select TCS®)—Tick Box Technology Corporation, 15 Chapel Street, Norwalk, CT 06850, 203-852-7171, www.tickboxtcs.com

Tick Tubes (Damminix®)—EcoHealth, 56 Hawes Street, Brookline, MA 02446, 617-742-2400, www.ticktubes.com

Tick Tweezers—BioQuip Products, 2321 Gladwick St., Rancho Dominguez, CA 90220, 310-667-8800, www.bioquip.com

References

Anderson, J.F. 1988. Mammalian and avian reservoirs for *Borrelia burgdorferi. Ann. N.Y. Acad. Sci.* 539:180.

Barbour, A.G. 1996. *Lyme Disease: the Cause, the Cure, the Controversy.* Johns Hopkins Press, Baltimore. 258 pp.

Battaly, G.R. and D. Fish. 1993. Relative importance of bird species as hosts for immature *Ixodes dammini* in a suburban residential landscape of southern New York State. *J. Med. Entomol.* 36(4):740-747.

Benjamin, M.A., E. Zhioua and R.S. Osfeld. 2002. Laboratory and field evaluation of the entomopathogenic fungus *Metarhizium anisopliae* for controlling questing adult *Ixodes scapularis. J. Med. Entomol.* 39(5):723-728.

Bharadwaj, A. and K.C. Stafford, III. 2010. Evaluation of *Metarhizium anisopliae* strain F52 for control of *Ixodes scapularis. J. Med. Entomol.* 47(5):862-867.

Bharadwaj, A., L.E. Hayes and K.C. Stafford, III. 2015. Effectiveness of garlic for control of *Ixodes scapularis* on residential properties in western Connecticut. *J. Med. Entomol.* 52(4):722-725.

Bosler, E.M. 1993. Tick vectors and hosts. In: Coyle, pp. 18-26.

Brownstein, J.S., T.R. Holford and D. Fish. 2005. Effect of climate change on Lyme disease risk in North America. *EcoHealth* 2(1):38-46.

Burgdorfer, W. 1993. Discovery of *Borrelia burgdorferi.* In: Coyle, pp. 3-7.

Burgio, F., L. Meyer and R. Armstrong. 2016. A comparative laboratory trial evaluating the immediate efficacy of fluralaner, afoxolaner, sarolaner, and imidacloprid + permethrin against adult *Rhipicephalus sanguineus* ticks attached to dogs. *Parasites and Vectors* 9(626): 6 pp.

Carroll, J.F. and M. Kramer. 2001. Different activities and footwear influence exposure to host-seeking nymphs of *Ixodes scapularis* and *Amblyomma americanum. J. Med. Entomol.* 38(4):596-600.

Carroll, J.F., D.E. Hill, P.C. Allen et al. 2009. The impact of 4-poster deer self-treatment devices at three locations in Maryland. *Vector Borne and Zoonotic Dis.* 9(4):407-416.

Coyle, P.K. 1993. *Lyme Disease.* Mosby-Year Book, St. Louis. 235 pp.

Dennis, D.T., T.S. Nekomoto, J.C. Victor et al. 1998. Reported distribution of *Ixodes scapularis* and *Ixodes pacificus* in the United States. *J. Med. Entomol.* 35(5):629-638.

Dolan, M.C., R.A. Jordan, T.L. Schulze et al. 2009. Ability of two natural products, nootkatone and carvacrol, to suppress *Ixodes scapularis* and *Ambly-*

omma americanum in a Lyme disease endemic area of New Jersey. *J. Econ. Entomol.* 102(6):2316-2324.

Eisen, L. and R.J. Eisen. 2016. Critical evaluation of the linkage between tick-based disease risk measures and the occurrence of Lyme disease. *J. Med. Entomol.* 53(5):1050-1062.

Elias, S.P. C.B. Lubelczyk, P.W. Rand et al. 2013. Effect of a botanical acaricide on *Ixodes scapularis* and nontarget arthropods. *J. Med. Entomol.* 50(1):126-136.

EPA (Environmental Protection Agency). 2010. Review of enhanced reporting of 2008 pet spot-on incidents. Office of Prevention, Pesticides, and Toxic Substances. Washington, DC, March 12, 2010. 25 pp.

EPA (Environmental Protection Agency). 2016. Climate Change Indicators in the U.S., Lyme Disease. 7 pp.

Falco, R.C. and D. Fish. 1988. Ticks parasitizing humans in a Lyme disease endemic area of southern New York State. *Am. J. Epidemiol.* 128:1146-1152.

Gardulf, A., I. Wohlfart and R. Gustafson. 2004. A prospective cross over field trial shows protection of lemon eucaplytus extract against tick bites. *J. Med. Entomol.* 41(6):1064-1067.

Garnett, J.M., N.P. Connally, K.C. Stafford and M.L. Carter. 2011. Evaluation of deer targeted interventions on lyme disease incidence in Connecticut. *Public Health Reports* 126(3):446-454. [CAB Abstracts]

Ginsberg, H.S. and E. Zhioua. 1999. Influence of deer abundance on the abundance of questing adult *Ixodes scapularis. J. Med. Entomol.* 36(3):376-381.

Hinckley, A.F., J.I. Meek, J.A.E. Ray et al. 2016. Effectiveness of residential acaricides to prevent Lyme and other tickborne diseases in humans. *J. Infect. Dis.* 214:182-188.

Hu, R. and K.E. Hyland. 1998. Effects of the feeding process of *Ixodes scapularis* (Acari:Ixodidae) on embryonic development of its parasitoid, *Ixodiphagus hookeri* (Hymenoptera: Encyrtidae). *J. Med. Entomol.* 35(6):1050-1053.

Jacobson, R., J. McCall, J. Hunter III et al. 2004. The ability of fipronil to prevent transmission of *Borrelia burgdorferi*, the causative agent of lyme disease, to dogs. *Int. J. Appl. Res. Vet. Med.* 2(1):39-45. [CAB Abstracts]

Jordan, R.A., M.C. Dolan, J. Piesman and T.L. Schulze. 2011. Suppression of host-seeking *Ixodes scapularis* and *Amblyomma americanum* ticks after dual applications of plant derived acaricides in New Jersey. *J. Econ. Entomol.* 104(2):659-664.

Keesing, F., J. Brunner, S. Duerr et al. 2009. Hosts as ecological traps for the vector of Lyme disease. *Proc. Royal Soc. B.* 276:3911-3919.

Kramer, V.L. and C. Beesley. 1993. Temporal and spatial distribution of *Ixodes pacificus* and *Dermacentor occidentalis* and prevalence of *Borrelia burgdorferi* in Contra Costa County, CA. *J. Med. Entomol.* 30(3):549-554.

Krause, P.J., S. Narasimhan, G.P. Wormser et al. 2014. *Borrelia miyamotoi* sensu lato seroreactivity and seroprevalence in the Northeastern United States. *Emerg. Infect. Dis.* 20(7):1183-1190.

Kulkarni, M.A., L. Berrang-Ford, P.A. Buck et al. 2015. Major emerging vectorborne zoonotic diseases of public health importance in Canada. *Emerg. Microbes Infect.* 4:e33.

Lane, R.S. and P.E. Lavoie. 1988. Lyme borreliosis in California: acarological, clinical, and epidemiological studies. *Ann. N.Y. Acad. Sci.* 539:192-206.

Lane, R.S. 1989. Treatment of clothing with permethrin spray for personal protection against the western black-legged tick, *Ixodes pacificus. Exp. Appl. Acarol.* 6:343-352.

Lane, R.S. and G.B. Quistad. 1998. Borreliacidal factor in the blood of the western fence lizard, *Sceloporus occidentalis. J. Parasitol.* 84(1):29-34.

Lane, R.S. 2000. Risks of Lyme disease in California. Seminar, June 7, 2000. UC Davis, CA.

Leighton, P.A., J.K. Koffi, Y. Pelcat et al. 2012. Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector *Ixodes scapularis* in Canada. *J. Appl. Ecol.* 49:457-464.

Levin, M.L. and D. Fish. 1998. Density-dependent factors regulating feeding success of *Ixodes scapularis* larvae. *J. Parasitol.* 84(1):3643.

Markowski, D., H.S. Ginsberg, K.E. Hyland and R. Hu. 1998. Reservoir competence of the meadow vole for the Lyme disease spirochete *Borrelia burdorferi. J. Med. Entomol.* 35(5):804-8-8.

Mather, T.N., J.M.C. Ribeiro, S.I. Moore and A. Spielman. 1988. Reducing transmission of Lyme disease spirochetes in a suburban setting. *Ann. N.Y. Acad. Sci.* 539:402-403.

Miller, N.J., E.E. Rainone, M.C. Dyer et al. 2011. Tick bite protection with permethrin treated summer weight clothing. *J. Med. Entomol.* 48(2):327-333.

Olkowski, W., H. Olkowski and S. Daar. 1990. Managing ticks, the least-toxic way. *Common Sense Pest Control Quarterly* 6(2):1-24.

Peavey, C.H. and R.S. Lane. 1995. Transmission of *Borrelia burgdorferi* by *Ixodes pacificus* nymphs and reservoir competence of deer mice (*Peromyscus maniculatus*) infected by tick-bite. *J. Parasitol.* 81(2):175-178.

Piesman, J., T.N. Mather, R.J. Sinsky and A. Spielman. 1987. Duration of tick attachment and *Borrelia burgdorferi* transmission. *J. Clin. Microbiol.* 25:557-558.

Piesman, J. 1999. Lyme disease IPM. *IPM Practitioner* 21(8):14.

Piesman, J. and M.C. Dolan. 2002. Protection against lyme disease spirochete transmission provided by prompt removal of nymphal *Ixodes scapularis. J. Med. Entomol.* 39(3):509-512.

Piesman, J. 2006. Response of nymphal *Ixodes scapularis*, the primary tick vector of Lyme disease spirochetes in North America, to barriers derived from wood products or related home and garden items. *J. Vect. Ecol.* 31(2):412-417.

Quarles, W. 2000. Growing Lyme disease epidemic. *Common Sense Pest Control Quarterly* 16(3):6-21.

Quarles, W. 2003. Insect biocontrol with fungi. *IPM Practitioner* 25(9/10):1-6.

Quarles, W. 2017. Global warming means more pathogens. *IPM Practitioner* 35(7/8):1-7.

Rand, P.W., E.H. Lacombe, S.P. Elias et al. 2010. Trial of a minimal risk botanical compound to control the vector tick of Lyme disease. *J. Med. Entomol.* 47(4):695-698.

Randolph, S.E. and K. Storey. 1999. Impact of microclimate on immature tick-rodent host interactions, implications for parasite transmission. *J. Med. Entomol.* 36(6):741-748.

Salkeld, D.J., S. Cinkovich and N.C. Nieto. 2014. Tickborne pathogens in Northwestern California, USA. *Emerg. Infect. Dis.* 20(3):493-494.

Schulze, T.L., W.E. Parkin and E.M. Bosler. 1988. Vector populations and Lyme disease. *Ann. N.Y. Acad. Sci.* 539:204-211.

Schulze, T.L., R.A. Jordan, R.W. Hung et al. 2009. Effectiveness of the 4-Poster passive topical treatment device in the control of Ixodes scapularis and Amblyomma americanum in New Jersey. *Vector Borne and Zoonotic Dis.* 9(4):389-400. [CAB Abstracts]

Schulze, T.L., R.A. Jordan, M. Williams et al. 2017. Evaluation of the Select Tick Control System (TCS), a host targeted bait box, to reduce exposure to *Ixodes scapularis* in a Lyme disease endemic area of New Jersey. *J. Med. Entomol.* March 15, 2017.

Sonenshine, D.E. 1993. *Biology of Ticks*, vol. 2. Oxford University Press, New York. 465 pp.

Spielman, A., M.L. Wilson, J.F. Levine and J. Piesman. 1985. Ecology of *Ixodes dammini*-borne human babesiosis and Lyme disease. *Ann. Rev. Entomol.* 30:439-460.

Spielman, A. 1988. Prospects for suppressing transmission of Lyme disease. *Ann. N.Y. Acad. Sci.* 539:212-220.

Stafford, K.C., III, 1998. Tick IPM using bait stations. *IPM Practitioner* 20(7):16.

Stafford, K.C., III, J.S. Ward and L.A. Magnarelli. 1998. Impact of controlled burns on the abundance of *Ixodes scapularis* (Acari:Ixodidae). *J. Med. Entomol.* 35(4):510-513.

Stafford, K.C. III. 2004. *Tick Management Handbook*. An integrated guide for homeowners, pest control operators, and public health officials for the prevention of tick-associated disease. Connecticut Agric. Exper. Sta., New Haven, 66 pp.

Stafford, K.C III, A.J. Denicola, J.M. Pound et al. 2009. Topical treatment of white-tailed deer with an acaricide for the control of *Ixodes scapularis* in a Connecticut Lyme borreliosis hyperendemic community. *Vector Borne and Zoonotic Dis.* 9(4):371-379. [CAB Abstracts]

Stafford, K.C., III and S.A. Allan. 2010. Field applications of entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* F52 for the control of *Ixodes scapularis. J. Med. Entomol.* 47(6):1107-1115.

Stromdahl, E.Y. and G.J. Hickling. 2012. Beyond Lyme: aetiology of tickborne human diseases with emphasis on the Southeastern United States. *Zoonoses Pub. Health* 59(Supl. 2):48-64.

Talleklint-Eisen, L. and R.S. Lane. 2000. Efficiency of tick drag sampling for estimating population sizes of *Ixodes pacificus* in leaf litter. *J. Med. Entomol.* 37(3):484-487.

Telford, S.R., III, T.N. Mather, S.I. Moore, M.L.Wilson and A. Spielman. 1988. Incompetence of deer as reservoirs of *Borrelia burgdorferi. Ann. N.Y. Acad. Sci.* 539:429-430.

Vail, S.G. and G. Smith. 1998. Air temperature and relative humidity effects on behavioral activity of blacklegged tick (Acari:Ixodidae) nymphs in New Jersey. *J. Med. Entomol.* 35(6):1025-1028.

Zhioua, E., K. Heyer, M. Browning, H.S. Ginsberg and R.A. LeBrun. 1999a. Pathogenicity of *Bacillus thuringiensis kurstaki* to *Ixodes scapularis. J. Med. Entomol.* 36(6):900-902.

Zhioua, E., H.S. Ginsberg, R.A. Humber and R.A. Lebrun. 1999b. Preliminary survey for entomopathogenic fungi associated with *Ixodes scapularis* in southern New York and New England, USA. *J. Med. Entomol.* 36(5):635-637.

Bees and Neonicotinoids

BIRC has produced several articles reviewing the adverse effects of neonicotinoid pesticides on honey bees and wild bees. Neonicotinoid effects on honey bees include increased mortality and impaired immunity. Exposed bumble bees produce fewer queens. Two new research articles on neonicotinoids and bees have been published this year, and they are summarized below.

Neonicotinoids in Cornfields Affect Bees

Canadian researchers investigated the effects of neonicotinoids on bees near cornfields in Canada. Researchers measured amounts of agrochemicals in 55 bee colonies within 500 m (0.3 mi) of cornfields, and compared the results with colonies more than 3 km (1.8 mi) away from the fields. They detected 26 agrochemicals, including neonicotinoids, in the exposed colonies. Neonicotinoids were major residues.

To check toxicity, researchers exposed lab colonies to the same concentration of the neonicotinoid clothianidin found in field colonies. Exposed worker bees had a 23% reduced life span, and showed decreased hygienic behavior, which is a measure of social immunity. Exposure to neonicotinoids also interfered with queen production, increasing the time the colonies went queenless. Toxic effects of neonicotinoids were synergized by realistic field concentrations of the fungicide boscalid. Neonicotinoids were about twice as toxic to honey bees in the presence of boscalid.

Tsvetkov, N., O. Samson-Robert, K. Sood et al. 2017. Chronic exposure to neonicotinoids reduces honey bee health near corn crops. *Science* 356: 1395-1397.

Neonicotinoid Effects on Bees Vary with Country

Results of another major study showed that field concentrations of neonicotinoids can contribute to adverse effects in bees. Researchers studied honey bees, *Apis mellifera*, buff tailed bumble bees, *Bombus terrestris*, and the solitary bee, *Osmia bicornis* near oilseed rape sites averaging about 63 ha (25.5 acre) in Germany, Hungary, and the United Kingdom.

Sites were treated either with clothianidin, thiamethoxam, or no neonicotinoid. At all sites other pesticides were used according to the state of the art for oilseed rape production. Neonicotinoid concentrations were measured in the fields and in the bee colonies.

Compared to controls, overwintering honey bee losses in Hungary were 24% higher when bees were exposed to clothianidin. When neonicotinoid exposure was high, bumble bees produced fewer queens, and *Osmia* sp. produced fewer eggs. Adverse effects were also seen in the UK, but no health effects were seen in German bee populations.

The difference between countries probably depends on the general health of the bees. In Germany, farmers were encouraged to plant flowers for them to provide extra resources.

Woodcock, B.A., J.M. Bullock, R.F. Shore et al. 2017. Country specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science* 356: 1393-1395.

Editorial: Environmental Protection—Not

The Environmental Protection Agency under the current administration is not protecting the environment. An example is chlorpyrifos. According to EPA scientists, chlorpyrifos can have neurotoxic effects on the developing brains of children. It also likely has adverse effects on at least 778 different wildlife species. EPA scientists recommended banning it in 2016 (EPA 2016). Scott Pruitt, Trump appointee at the EPA has refused to follow the recommendations of the EPA's own scientists.

Protection of the environment and public health should rely on science, not partisan politics. But there may be a way forward. The U.S. Senate has become involved, introducing S1624, the *Protect Children, Farmers and Farmworkers from Nerve Agent Pesticides Act*, which will ban chlorpyrifos.

The FDA is not much better at protecting the public. It may deregulate genetically engineered food produced through gene editing. Gene editing is a way to modify or delete genes in an organism without introducing a transgene. Rationale for deregulation is that genes foreign to the organism are not being introduced, and the methods used such as Crispr-CAS 9 are highly targeted.

However, there are significant off-target mutagenic effects with Crispr (Fu et al. 2013). Some of these have gone unrecognized up to now, because only part of the engineered genome is usually analyzed after a genetic transformation. New research that sequences an entire genome shows massive off-target mutagenic effects such as base pair deletions and additions, along with outright deletion of large amounts of genetic information (Schaefer et al. 2017). This research has met with a storm of controversy, but off-target effects with Crispr have been documented before (Hsu et al. 2013; Fu et al. 2013).

Gene edited food, including gene edited food animals should be regulated. Companies should look for off-target genetic changes by scanning the whole genome of the transformed organisms. The off-target genetic changes should then be evaluated for possible toxic effects. If the FDA deregulates food produced by gene editing, companies would not have to do research on possible adverse effects.

EPA (Environmental Protection Agency). 2016. *Chlorpyrifos: Revised Human Health Risk Assessment for Registration Review*. 41 pp. November 3, 2016.

Fu, Y.F., J.A. Foden, C. Khayter et al. 2013. High frequency off-target mutagenesis induced by Crispr-Cas nucleases in human cells. *Nature Biotechnology* 31(9):822-826.

Hsu, P.D., D.A. Scott, J.A. Weinstein et al. 2013. DNA targeting specificity of RNA-guided Cas9 nucleases. *Nature Biotechnology* 31: 827–832.

Schaefer, K.A., W.H. Wu, D.F. Colgan et al. 2017. Unexpected mutations after Crispr-Cas9 editing in vivo. *Nature Methods* 14(6):547-548. May 31, 2017

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