Safety Assessment of Insecticides Used to Control Mosquitoes

CHAPTER 2

The effect of insecticides on humans and the environment is a primary issue in mosquito control. Our review addressed the following questions:

- **What does scientific research say about the effects of insecticides used by the Metropolitan Mosquito Control District on humans and nontarget species?**

- **What insecticides are used in other Minnesota cities and other states to control mosquitoes?**

To evaluate the safety of insecticides used by the Metropolitan Mosquito Control District (MMCD), we reviewed documents from the U.S. Environmental Protection Agency (EPA), articles from scientific journals, and research reports. To determine the insecticides used for mosquito control in other jurisdictions, we examined Minnesota Department of Agriculture municipal insecticide control data and we conducted telephone interviews with representatives of state agencies and mosquito control districts in other states.

Our conclusion from reviewing the scientific literature is generally consistent with EPA's position that the insecticides MMCD uses in mosquito and black fly larval control pose little risk to people and most nontarget species when used according to federally-mandated label instructions. A long-term study of Minnesota wetlands found that *Bti* and methoprene did not produce adverse effects on aquatic micro-organisms (such as zooplankton) or on the reproduction of red-winged blackbirds. Research results on the effects of these insecticides on midges, a nonbiting fly, were inconclusive.

Some scientists remain concerned about the insecticides MMCD uses for larval control because of the potential adverse effects on other species, especially midges. For some people this concern also extends to killing mosquitoes because they are part of the food chain in Minnesota wetlands. Limited scientific research has been conducted on the impacts of killing mosquito larvae on species higher on the food chain, such as wetland waterfowl.

The insecticides that MMCD uses to kill adult mosquitoes, resmethrin and permethrin, are controversial because they have the potential to harm other types of insects and aquatic organisms. The Minnesota Department of Health (MDH) assessed the risk of permethrin and resmethrin to humans and concluded that "exposure . . . through ingestion or skin contact does not pose a health risk to humans . . . . Brief inhalation of the insecticides should not pose a health risk."[1] The World Health Organization has also reviewed these insecticides and found them safe for humans and the environment when used at the recommended doses. Because permethrin and resmethrin are broad spectrum insecticides, however, they must be applied judiciously and in strict conformity with EPA label requirements. If the products are applied according to label directions they should not pose a health risk to humans.

It is not possible to reconcile different scientific perspectives about the need to use insecticides.

The use of insecticides will alter the ecology of the environment by, if nothing else, killing mosquitoes. Some scientists recognize this and say that MMCD is using the most appropriate chemicals available for mosquito control. Other scientists, conservationists, and environmentalists argue that the use of any insecticides is unacceptable. One resource refers to this as the "pesticide problem" and states:

> To a large degree, [the pesticide problem] is the result of disagreement among people about the need for pest control, about what environmental features deserve serious concern, about what pesticides ought to do, and about what side effects from them are tolerable. [2]

We are unable to reconcile these competing points of view because they represent different scientific perspectives and value judgments. Ultimately, decisions about whether to continue using insecticides for mosquito and black fly control are policy decisions that are most appropriately made by the Legislature using the best scientific information available.

BACKGROUND

The main federal law on insecticide regulation is the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), which governs the registration, distribution, sale, and use of insecticides. The U.S. Environmental Protection Agency is responsible for its administration. EPA registers new insecticides and, sometimes, re-registers insecticides that have been on the market for many years. When considering insecticides for registration, FIFRA requires the Environmental Protection Agency to balance the risks of insecticides to humans and the environment against the benefits of using insecticides. If the benefits outweigh the risks, EPA may approve the insecticide for specific applications which must be stated on the product label. EPA makes its decision to approve an insecticide based on a review of scientific research, which is often carried out by the insecticide manufacturer. If the insecticide ends up in food, EPA must also set a tolerance or maximum limit on the amount allowed in food. EPA has established food tolerances for several of the mosquito control insecticides used by MMCD because they are also used in agricultural production.

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1 Minnesota Department of Health, "Risk Assessment on Scourge and Punt Materials Used by the Metropolitan Mosquito Control District for the Control of Adult Mosquitoes," March 17, 1993.

2 Wayland J. Hayes, Jr. and Edward R. Laws, Jr., eds., *Handbook of Pesticide Toxicology* (San Diego, Calif.: Academic Press, Inc., 1991), 27.

Although EPA registered all the insecticides currently used for mosquito control many years ago, scientific research continues on the safety of these insecticides and their broader effects on the environment. Scientists have focused their work on the potential harm to nontarget species, such as other types of insects, frogs, ducks, and birds. Assessment of environmental impact requires looking at the effect on organisms directly exposed to insecticides as well as the effect on organisms higher up the food chain that might eat mosquitoes killed by insecticides or that might not have as many mosquitoes available to eat. The composition of an insecticide as it breaks down chemically is also an important environmental issue.

Several principles of toxicology bear on the research. Foremost is the question of dose. The *Handbook of Pesticide Toxicology* states:

> Control of dosage is the basis for almost all safety in the use of chemicals. This rule applies not only to compounds of relatively high toxicity but also to compounds of low toxicity including those necessary to life.[3]

The dosage of an insecticide is a principal factor in determining the insecticide's toxicity.

Table salt or even water could be toxic in large enough quantities. In contrast, humans can tolerate traces of potentially toxic chemicals. As with any drug or medicine, the amount of a pesticide that an organism takes in is critical to the pesticide's effect. Typically, there is a dosage level below which no observed harmful effect occurs, but as the dosage of a pesticide increases, harmful or toxic effects such as tumors, developmental irregularities, failure to reproduce, birth defects, or death may occur. The dose at which harm occurs may vary widely across species or it may be limited to certain organisms. In registering an insecticide, EPA establishes a dosage rate that is sufficient to be effective against specific insects but is no stronger than necessary to achieve the insecticide's purpose. In general, the smallest amount of insecticide necessary for control should be used. Federally-mandated insecticide labels specify the dosage rates.

The toxicity of an insecticide is also related to how an organism is exposed to it. In assessing risk toward humans, one must consider the effects of ingesting or inhaling an insecticide, and its effects should it come into contact with skin or eyes. Additionally, one must consider short-term and long-term effects. Typically, insecticides affect insects at certain stages in their life cycle. As discussed in the previous chapter, mosquitoes develop from eggs to larvae, pupae, and then adults. This is called a complete metamorphosis. Some insecticides are designed to kill mosquitoes in their larval stage, while others are used to kill adult mosquitoes. Furthermore, a mosquito passes through several developmental stages or "instars" during the larval stage, and an insecticide may be effective at only some of the instars. Generally, the more specific an insecticide is to a particular type of insect at a particular stage of its development, the safer it will be to other organisms.

Another important research consideration is how environmental factors modify the effectiveness and safety of an insecticide. Testing an insecticide in a laboratory is far different from applying it in a swamp. Once an insecticide is released in

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3 Hayes and Laws, *Handbook*, 68-69.

natural surroundings, temperature, sunlight, pollutants, organic matter in water, and other factors can render it less effective against mosquitoes or change its effect on nontarget organisms. In our review, we examined both laboratory studies and research done in the field.

MMCD uses *Bacillus thuringiensis israelensis* (*Bti*) and methoprene to control mosquito larvae and resmethrin and permethrin, synthetic chemicals, to control adult mosquitoes. We found that:

- **MMCD uses insecticides that are approved by EPA for control of mosquitoes and black flies.**

Beginning with the insecticides used for larval control, the remainder of this chapter reviews the insecticides that MMCD uses to control mosquito and black fly larvae and adult mosquitoes. The final section of the chapter discusses alternatives to chemical control and insecticides used in other Minnesota cities and other states.

LARVAL INSECTICIDES

MMCD's primary focus of mosquito control is to attack mosquitoes while they are still in the larval state. Since the mid-1980s, MMCD has used two insecticides to control mosquito larvae, *Bti* and methoprene.[4] *Bti* is also used to control black flies (or biting gnats) in their larval stage.

Bti and methoprene are both effective at killing mosquito larvae, but their method of killing larvae differs. *Bti* is more specifically a killer of mosquitoes than methoprene, which potentially has more adverse impact on other types of insects, depending on dosage and formulation. MMCD uses the two insecticides in different situations. *Bti* degrades rapidly in the environment and must be reapplied periodically, but methoprene comes in several timed-release forms that can persist in the environment for up to 150 days. MMCD uses timed-release forms of methoprene to treat isolated and hard-to-reach mosquito breeding sites.

Bti

Bacillus thuringiensis israelensis, or *Bti*, is a naturally occurring soil bacteria. "*Israelensis*" is one of many different varieties of the *Bt* bacterium.[5] *Bti* has a microscopic crystal protein that is specific against mosquitoes, black flies, and midges. Once ingested, the crystal protein is activated in the insect's gut which is highly alkaline. The activated protein binds to receptors on cell membranes of the midgut, pores develop and cells break apart, and essentially the gut wall dissolves.

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4 MMCD also conducts field tests of new products to determine if a product could be used operationally. For example, since 1997 the District has been testing a new larval control product called Laginex whose active ingredient is a fungus.

5 F. G. Priest, "A Review: Biological Control of Mosquitoes and Other Biting Flies by *Bacillus sphaericus* and *Bacillus thuringiensis*," *Journal of Applied Bacteriology* 72 (1992): 357-369.

The larva is not able to feed and dies.[6] Although *Bti* is a biological organism, it does not reproduce in the environment.

To be effective, *Bti* must be applied within a narrow window of opportunity in the development of mosquitoes. Typically, a rainfall of one inch or more will cover mosquito eggs that were laid earlier in damp earth at the edge of a depression, pond, or wetland. The eggs, covered by water, will hatch within one day, become larvae, then swim and feed in the water for six to eight days before they change to pupae and emerge as adults.[7] *Bti* must be ingested to be effective and mosquito larvae stop feeding at the fourth instar. *Bti* degrades within about a week in the water and must be reapplied when new broods of mosquitoes or black flies hatch.

***Bti* degrades rapidly in the environment and must be applied when mosquito larvae are feeding.**

EPA's registration process applies to all varieties of *Bacillus thuringiensis (Bt)*. *Bt* is not toxic to birds, dogs, mice, rats, or other animals. Tests on humans verified its non-toxicity. It does not persist in the digestive systems of animals that may ingest it. It breaks down rapidly in the environment and poses no problems of residue or disposal.[8] It is not a threat to the groundwater, and EPA has issued no restrictions for its use around bodies of water. The EPA mandated product label specifies a range of dosage rates, up to 20 pounds per acre, depending on the site and larval stage of the mosquitoes. The label states that it cannot be applied directly to treated, finished drinking water reservoirs or drinking water receptacles.

EPA originally registered *Bt* in 1961 and re-registered it in 1998, taking into account new scientific evidence.

- **According to the new EPA assessment of *Bt*, "Toxicity and infectivity risks . . . to nontarget avian, freshwater fish, freshwater aquatic invertebrates, estuarine and marine animals, arthropod predators/parasites, honey bees, annelids, and mammalian wildlife will be minimal to nonexistent at the label use rates of registered *B. thuringiensis* active ingredients."[9]**

Minnesota Research on *Bti*

A 1989-90 study funded by the U.S. Fish and Wildlife Service at the Minnesota Valley National Wildlife Refuge tested the effects of *Bti* on chironomids, also called midges. Midges are nonbiting flies that are biologically similar to

6 Scientific Peer Review Panel, "An Assessment of Nontarget Effects of the Mosquito Larvicides, *Bti* and Methoprene, in Metropolitan Wetlands," unpublished report to the Metropolitan Mosquito Control District, January 1996: 5.

7 Claudia M. O'Malley, "*Aedes vexans* (Meigen): An Old Foe," *Proceedings of the New Jersey Mosquito Control Association* (1990): 90-95.

8 Extension Toxicology Network (EXTOXNET), "*Bacillus thuringiensis*," revised 5/94, Pesticide Management Education Program, Cornell University, Ithaca NY, <http://pmep.cce.cornell.edu/>. This information is provided by a consortium of extension offices from Cornell University, Michigan State University, Oregon State University, and the University of California at Davis. The half life for *Bt* under normal sunlit conditions is 3.8 hours.

9 Environmental Protection Agency, "R.E.D. Facts — *Bacillus thuringiensis*," EPA-738-F-98-001 (Washington, D.C., 1998), 3.

mosquitoes and generally susceptible to the same insecticides. Midges are important to the environment as a high protein food for other species in the food chain, such as waterfowl. Under laboratory conditions, researchers observed that *Bti* adversely affected midges. However, when researchers applied *Bti* to enclosed ponds in the refuge at the normal dosage rate and at five times the normal rate, no adverse effects were seen on midge larvae or their emergence as adults.[10] This is an example of how laboratory and field experiments can show significantly different adverse effects on nontarget species.

Between 1986 and 1996, an independent research panel sponsored laboratory and field experiments on the effects of larval insecticides.

As discussed in Chapter 1, the Scientific Peer Review Panel (SPRP), an independent research panel funded by the District, sponsored laboratory studies and field experiments between 1986 and 1996 to describe impacts of the insecticides used to kill mosquito larvae. The laboratory studies were designed to identify species that might be subject to adverse effects of insecticides used by MMCD. Results showed no adverse effects on crayfish and three species of frogs and toads that were fed *Bti*-killed mosquito larvae. However, one species of midge experienced high mortality at *Bti* concentrations near or below those that kill mosquitoes, although a longer exposure time was required, indicating a need to monitor midge populations in the long-term field experiment that followed.[11]

In 1988, SPRP supported three initial, short-term field studies. In one study, researchers from the Natural Resources Research Institute (NRRI) at the University of Minnesota Duluth, compared 10 mosquito breeding sites that had been treated with *Bti* for two or more years with 30 similar sites that had not been treated. The study examined the reproduction and growth of red-winged blackbirds, and the number and types of zooplankton, aquatic insects, and other species of invertebrates at the sites. Researchers detected no significant differences between the treated and untreated sites.[12]

In another study, a census of 26 types of birds compared 34 sites treated with *Bti* or methoprene with similar but untreated sites in 1988. Only yellow-headed blackbirds showed a lower population on treated sites. However, small changes in bird populations would probably not have been detected.[13] The researchers did not distinguish between sites treated with *Bti* and methoprene. In addition, many of the birds researchers examined were not dependent on wetlands and the small number of sample sites limited analysis.

In a subsequent experiment in 1988-89, NRRI researchers divided six small wetlands or ponds into three sections that were either treated with *Bti* or methoprene or left untreated. Analysis of the number and types of zooplankton, aquatic insects, and other invertebrates did not show significant changes between the treated and untreated areas. However, the densities of aquatic insects and invertebrates were too low to provide a rigorous test. Since the study only lasted

10 Colette Charbonneau, Ronald D. Drobney, and Charles F. Rabeni, "Effects of *Bacillus thuringiensis* var. *Israelensis* on Nontarget Benthic Organisms and Factors Affecting Efficacy of the Larvicide," *Environmental Toxicology and Chemistry* 13 (1994): 267-279.

11 Scientific Peer Review Panel, "An Assessment," 1, 6.

12 *Ibid*., 12-13.

13 *Ibid*., 13-14.

one year, it did not address the long-term effects of the insecticides.[14] Based on the above studies,

- **The Scientific Peer Review Panel concluded that no effects of [*Bti* and methoprene] on aquatic insects, on zooplankton, or on birds were seen in the initial, short-term SPRP field studies.[15]**

The independent research panel designed a long-term study on the effects of *Bti* and methoprene on wetlands in Wright County.

The relatively short time frame of the above studies led the Scientific Peer Review Panel to design a study to gauge the long-term effects of both *Bti* and methoprene. The project, called the Wright County Long-Term Experiment, started in 1987. SPRP initially contracted with NRRI to test these insecticides in 26 wetlands in Wright County, outside MMCD's control area. The experiment included two years of pre-treatment sampling of invertebrates (including aquatic insects, snails, and fingernail clams), zooplankton populations, and wetland birds, followed by three years of treatment (1991-93). It matched treated and untreated sites that were similar to each other before the experiment began. Researchers compared the sites as to the numbers, density, and diversity of insects and various aquatic micro-organisms. The researchers looked for food-chain effects by counting insects that prey on mosquito larvae and by studying breeding birds on the wetland sites. Red-winged blackbirds were chosen because they were the most abundant bird species common to most sites. However, red-winged blackbirds may not be the most useful sentinel species, because they are not a wetland dependent species.[16]

Two research groups have produced studies on the Wright County experiment. The first study, by NRRI, covered the first three years of treatment data (1991-93). The second study, by the Lake Superior Research Institute (LSRI) of the University of Wisconsin Superior, sampled the sites in 1997, after seven years of treatment. MMCD continued to treat the sites in 1998, making the Wright County experiment one of the few long-term studies that has been done on the effects of *Bti* or methoprene.

In its first research report and in related articles in scientific journals:

- **The Natural Resources Research Institute found that no adverse effects on aquatic micro-organisms (zooplankton), on the reproduction of red-winged blackbirds, or on the numbers of 18 other bird species could be associated with *Bti* and methoprene treatments.[17]**

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14 *Ibid*., 14.

15 *Ibid*., 2.

16 *Ibid*., 16-17.

17 *Ibid*., 2, 19, 29, 31; JoAnn M. Hanowski, Gerald J. Niemi, Ann R. Lima, and Ronald R. Regal, "Do Mosquito Control Treatments of Wetlands Affect Red-Winged Blackbird (*Agelaius phoneiceus*) Growth, Reproduction, or Behavior?" *Environmental Toxicology and Chemistry* 16, no. 5 (1997): 1014-1019.

Research results on the impacts to midges were inconclusive over the life of the Wright County experiment.[18]

- **NRRI found that after three years, *Bti* and methoprene had an adverse effect on the numbers of aquatic insects, particularly midges and other primitive flies.[19]**

Research on the effects of *Bti* and methoprene on midges, a nonbiting fly, has been inconclusive.

By the end of the summer of the third year of treatment, the midge population had decreased to about 16 percent of that in untreated areas. The study found about the same level of adverse effects for *Bti* and methoprene.

However, LSRI came to a different conclusion after analyzing samples collected in 1997.

- **In sharp contrast to the previous study, and despite four more years of insecticide treatment, researchers from the Lake Superior Research Institute found few statistically significant differences in the numbers of midges between treated and untreated sites for either *Bti* or methoprene.**

One species of midge decreased but only in the last sample of the summer of 1997. No effects were seen on predator insects higher up the food chain. The authors concluded, "very few significant differences were observed, and certainly not in the major groups such as total macroinvertebrates, total insects, nematocera, chironomidae, and predators."[20] This result applied to both *Bti* and methoprene.

Researchers in the two studies used different methods for finding and counting insects. The second research group demonstrated that its procedure resulted in more accurate insect counts by comparing the counts from samples using both methods. However, scientists told us that using different methods should not account for differences in research results. MMCD has contracted with LSRI for another year of research in 1998 on the same experimental sites.

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18 In addition to these findings, the SPRP report (on pages 31-32) cites some issues with the design of the Wright County experiment that could limit the ability to generalize the results to MMCD's entire control program. Some of these issues include: 1) the sites were not representative of all wetlands in the MMCD control program; 2) *Bti* was applied at a higher rate than used in normal MMCD operations; 3) it is puzzling that *Bti* and methoprene had similar levels of adverse effects, because they work in very different ways; and 4) red-winged blackbirds are not a wetland dependent species and therefore not representative of effects on other wetland dependent waterfowl.

19 Scientific Peer Review Panel, "An Assessment," 21, 24, 29, 31; G. J. Niemi, R. P. Axler, J. M. Hanowski, A. E. Hershey, A. Lima, R. R. Regal, and L. J. Shannon, "Evaluation of the Potential Effects of Methoprene and *Bti* (*Bacillus thuringiensis israelensis*) on Wetland Birds and Invertebrates in Wright County, MN, 1989 to 1993, Volume I," Natural Resources Research Institute and Department of Biology, Department of Statistics, University of Minnesota Duluth, December 1995; Anne E. Hershey, Ann R. Lima, Gerald J. Niemi, and Ronald R. Regal, "Effects of *Bacillus thuringiensis israelensis* (*Bti*) and Methoprene on Nontarget Macroinvertebrates in Minnesota Wetlands," *Ecological Applications* 8 (1998): 41-60.

20 Kurt L. Schmude, Mary D. Balcer, and Ann R. Lima, "Effects of the Mosquito Control Agents *Bti* and Methoprene on Nontarget Macroinvertebrates in Wetlands in Wright County, Minnesota (1997)," Lake Superior Research Institute, unpublished: 26. Macroinvertebrates are invertebrates larger than 3 mm; nematocera are long-horned flies, such as crane flies. This study did not look at birds.

Although the long-term experiment had a strong likelihood of detecting declines of 50 percent or more in an insect population, it is possible that small declines in insect populations went undetected. The possible impact of small changes in an insect population on the broader environment is unknown, but insects often experience large variations in their populations because of natural causes.

In 1994, the Scientific Peer Review Panel contracted with LSRI to test the toxicity of *Bti* to midges, the nontarget insect most adversely affected in some previous studies. This study explored the effect of applying different doses of *Bti* in a pond, which would be similar to typical treatment sites. The research showed that some species of midges were more susceptible to *Bti* than others. Midge larvae had a significant reduction in abundance at 10 times the normal rate of *Bti*, but not statistically significant effects at 5 times the normal rate.

- **LSRI concluded that the application rates of *Bti* required for significant reductions in midge abundance were 2.5 to 5 times greater than the rates routinely used for mosquito control in Minnesota.**

The authors concluded that the normal application rate of *Bti* provides a reasonable margin of safety for midges.[21] The *Bti* application rates used by MMCD are either five or eight pounds per acres.

Research on *Bti* in Black Fly Control

The Department of Natural Resources required MMCD to study the effects of *Bti* liquid on the environment.

While mosquitoes breed only in standing water, black flies or biting gnats breed only in running water. Several species of black flies start their lives in local streams and rivers, including the Minnesota, Mississippi, Rum, and Crow rivers. When sufficient numbers of black fly larvae are found in a stream or river, MMCD staff pour a liquid form of *Bti* into the water. As *Bti* drifts downstream, it kills black fly larvae for a considerable distance, depending on the swiftness of the water.

The Minnesota Department of Natural Resources (DNR) issues the District an annual permit to apply liquid *Bti* in moving public waters. DNR required research on environmental safety as a condition of MMCD's permit to control black flies. Consequently, MMCD has conducted extensive research on *Bti* used to kill black fly larvae and its possible adverse effects on nontarget species.

21 Karsten Liber, Kurt. L. Schmude, and Daniel M. Rau, "Toxicity of *Bacillus thuringiensis* var. *Israelensis* to Chironomids in Pond Mesocosms," Lake Superior Research Institute, 1996, unpublished: 12-13, 17.

- **A series of reports by MMCD shows that in flowing water, *Bti* had no adverse effects on a variety of nontarget organisms including mayflies, stoneflies, dragonflies, damselflies, beetles, and other two-winged flies. Its effect on midges, especially one species, was inconsistent.[22]**

These findings are consistent with other studies that have found no negative impact of *Bti* on several nontarget insects when *Bti* is applied at recommended doses.[23] The most susceptible nontarget insects appear to be certain species of midges that, like black flies, are filter feeders.[24] Other studies have identified no adverse effects on selected fish and insects that feed on black fly larvae killed with *Bti*.[25]

Methoprene

The District uses methoprene pellets and briquets that dissolve slowly in water.

Although *Bti* might be the preferred insecticide for mosquito larval control, its short lifetime in the environment and the need to apply it within a few days after larval development begins limit its use. As an alternative, MMCD also controls mosquito larvae with methoprene. Typically, MMCD applies methoprene in the form of 150-day timed-release briquets or 30-day timed-release pellets that slowly dissolve in water. MMCD also uses a small amount of liquid methoprene.

Methoprene is a synthetic insect growth regulator that disrupts the normal development of some insects. Methoprene increases the concentration of growth hormone during the fourth larval instar, thereby disrupting the transformation to a pupa and killing the insect during the pupal stage. Methoprene may be less disruptive to the food chain in wetlands than *Bti* because it kills slowly, allowing

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22 Kenneth R. Simmons, "The Effects of *Bacillus thuringiensis* var. *Israelensis* (*Bti*) on Black Flies and Nontarget Invertebrates in Trott Creek and Cedar Creek," unpublished report, Metropolitan Mosquito Control District, February 1991; Kenneth R. Simmons, "Effect of Multiple Applications of the Bacterial Insecticide, *Bacillus thuringiensis* var. *Israelensis* (*Bti*) on Black Flies and Nontarget Invertebrates in the Mississippi River: Results of 1989 Studies," unpublished report, Metropolitan Mosquito Control District, June 1991; Kenneth R. Simmons and David Crews, "Effects of Three Years of Operational Control of the Black Fly *Simulium luggeri* with *Bacillus thuringiensis* var. *Israelensis* (*Bti*) on Nontarget Invertebrates in the Mississippi River," unpublished report, Metropolitan Mosquito Control District, October 1995; Kenneth R. Simmons and David Crews, "The Effects of Black Fly Control with *Bacillus thuringiensis* var. *Israelensis* (*Bti*) on Production of the Stonefly *Paragnetina media* (Walker) in the Rum River," unpublished report, Metropolitan Mosquito Control District, January 1996.

23 Mark S. Wipfli and Richard W. Merritt, "Effects of *Bacillus thuringiensis* var. *Israelensis* on Nontarget Benthic Insects and Through Direct and Indirect Exposure," *Journal of the North American Benthological Society* 13 (1994): 190-205; and Danial P. Malloy, "Impact of the Black Fly (Diptera: Simuliidae) Control Agent *Bti* on Chironomids (Diptera: Chironomidae) and Other Nontarget Insects: Results of Ten Field Trials," *Journal of the American Mosquito Control Association* 8 (1992): 24-31.

24 Malloy, "Impact of Black Fly," 29-30.

25 Mark S. Wipfli and Richard W. Merritt, "Low Toxicity of the Black Fly Larvicide *Bacillus thuringiensis* var. *Israelensis* to Early States of Brook Trout (*Salvelinus fontinalis*), Brown Trout (*Salmo trutta*), and Steelhead Trout (*Oncorhynchus mykiss*) Following Direct and Indirect Exposure," *Canadian Journal of Fisheries and Aquatic Sciences* 51 (1994): 1451-1458; Simmons and Crews, "The Effects of Black Fly Control."

more larvae to reach the pupal stage before they die and thus potentially be available for a longer time as prey for other species.[26]

Methoprene is registered for control of a variety of pests such as ants, flies, lice, moths, beetles, and fleas. As a pest control, it is used in the production of a number of foods, including meat, milk, eggs, mushrooms, peanuts, rice, and cereals. EPA has established a tolerance for methoprene in food products, so human exposure to methoprene is more likely to be from food than from mosquito control.[27]

EPA has recently issued new label requirements for the timed-release methoprene products. In previous years, these products were not to be used in known fish habitats. The current label removes that restriction.[28]

Methoprene has been studied extensively since the early 1970s and was first registered by EPA in 1975.

- **According to EPA, methoprene is of low toxicity and poses little risk to people and other nontarget species with the exception of estuarine invertebrates (such as shrimp) not found in Minnesota.**

Information on the use of the slow-release methoprene briquet is currently under review by the EPA because studies suggest that the use of this product in estuarine areas may cause undue risks to estuarine invertebrates. According to EPA's review, methoprene has shown no adverse effects on human health if ingested or inhaled, but may be slightly toxic if absorbed through the skin. No methoprene effects were seen in a two-year feeding experiment with rats. It does not cause tumors or cancer. It metabolizes rapidly and completely in mammals and somewhat more slowly in plants. It degrades rapidly in sunlight and soil, so it does not persist as a contaminant.[29]

Methoprene has shown no toxicity to mallards at relatively high doses, but it is moderately toxic to freshwater fish and some freshwater invertebrates, such as crayfish. Risks to fish are limited, however, because methoprene is not very soluble in water and it is not very persistent. When methoprene briquets dissolve in water, they produce a level of concentration far below the level that is hazardous to fish. Similarly, methoprene is potentially harmful to frogs, toads, and salamanders, but low dosage rates used in mosquito control should prevent harm to these species.[30]

Researchers in Florida tested the effect of multiple doses of methoprene on several nontarget organisms exposed over intervals from 20 days to 4 weeks in

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26 Mir S. Mulla, "The Future of Insect Growth Regulators in Vector Control," *Journal of the American Mosquito Control Association* 11 (1995): 269-273.

27 Environmental Protection Agency, "R.E.D. Facts—Methoprene," H-7508W, March 1991.

28 Product label for Altosid Pellets and XR Extended Residual Briquets, Sandoz Agro, Inc., EPA Reg. No. 2724-448-64833, April 1997.

29 Environmental Protection Agency, "R.E.D. Facts—Methoprene," H-7508W, March 1991.

30 Extension Toxicology Network (EXTOXNET), "Methoprene," revised 9/95, Pesticide Management Education Program, Cornell University, Ithaca NY, <http://pmep.cce.cornell.edu/>.

specially-designed ponds. Test organisms included freshwater shrimp, crayfish, mosquitofish, minnows, and dragonfly naiads. A comparison of organisms in treated and untreated ponds showed no differences in the number of organisms, their development, or their mortality rates. Researchers thought that if there was an adverse effect it might be seen in dragonflies, but that was not the case in either their larval or adult stages.[31]

Minnesota Research on Methoprene

The independent research panel also studied the effects of methoprene on nontarget species.

As discussed earlier, research sponsored by the Scientific Peer Review Panel focused on the environmental impacts of *Bti* and methoprene. Laboratory studies tested the effects of methoprene on water fleas, two zooplankton species, and leopard frogs. Under laboratory conditions, researchers found decreases in reproduction of one species of zooplankton when exposed to concentrations of methoprene about two times higher than the dosage rates used by MMCD. The other species of zooplankton was much less sensitive to methoprene, showing no effect at exposures two times the operational dosage rate, but some effects were seen at slightly higher rates.[32] In its mosquito control efforts, MMCD tries to achieve a concentration of two parts per billion of methoprene in the water. Based on laboratory results, researchers designed the subsequent field studies to test the effects of methoprene on zooplankton.

- **SPRP laboratory studies also showed that methoprene did not affect the development of frog embryos and larvae (tadpoles) until the dosages were many times greater than used in mosquito control.**

Researchers followed the development of tadpoles for 100 days, beginning 48 hours after their birth. Tadpoles were exposed to high levels of methoprene over that period. Researchers observed no adverse effects until the dosage rate was over 200 times normal mosquito control rates, at which point tadpole development was delayed and body mass was reduced. Tadpoles exposed to even higher doses of methoprene moved more slowly and less frequently than at lower doses, but none died.

A field study attempted to determine the effect of methoprene on the growth and development of mallard ducklings. Declining water levels hampered this study. SPRP members determined that the results from this study were inconclusive.[33]

Along with its analysis of *Bti*, NRRI compared 10 wetlands that had been treated with methoprene with 30 wetlands that had never been treated with insecticides. Researchers examined reproduction and growth of red-winged blackbirds and

31 Philip G. Hester, Carlisle B. Rathburn, Jr., and Arthur H. Boike, Jr., "Effects of Methoprene on Nontarget Organisms When Applied as a Mosquito Larvicide," (Department of Health and Rehabilitative Services, West Florida Arthropod Research Laboratory, Panama City, FL), Proceedings of the Florida Anti-Mosquito Association (nd): 16-20.

32 Scientific Peer Review Panel, "An Assessment," 1, 10.

33 *Ibid.*, 15. The Legislative Commission on Minnesota Resources helped finance the mallard duckling study.

numbers of aquatic insects and observed no differences between treated and untreated sites.[34]

The Wright County Long-Term Experiment looked at both methoprene and *Bti*.[35] As discussed previously, the two research groups analyzing the experiment reached different conclusions concerning the effects on midges. The first research report showed adverse effects for methoprene on some insects, particularly midges. The more recent study, however, found little or no significant adverse effects on midges between treated and untreated sites.

The long-term study was particularly important to assess methoprene effects because the timed-release formulations keep a steady level of methoprene in water (ideally two parts per billion) over extended time periods, up to an entire summer. In contrast, *Bti* degrades rapidly after application and had to be reapplied in the experiment. One might have expected to see more adverse results from methoprene than *Bti*, given that methoprene is released slowly in the water over a period of time. That was generally not the case, however, in either the first or second analysis.

Another MMCD experiment tested whether the methoprene briquets leave a residue in water from one year to the next. MMCD researchers found that the average 150-day briquet degraded to 19 percent methoprene after 150 days and completely degraded after 1.5 years under water.[36]

Deformed Frogs

Concern about deformed frogs has heightened interest in methoprene as one of several possible causes. Much research is underway on this issue, and our review of the latest research shows that:[37]

- **So far, researchers have not been able to determine what causes frog deformities.**

Alternative hypotheses would implicate parasitic flatworms, ultraviolet light, or other chemicals in the water. Although frog deformities have been reported for hundreds of years, some scientists are pointing to methoprene as a culprit because

34 *Ibid*., 12-13.

35 Niemi et al., "Evaluation of the Potential Effects;" Hershey et al., "Effects of *Bacillus thuringiensis israelensis*;" Hanowski et al., "Do Mosquito Control;" Kurt L. Schmude et al., "Effects of the Mosquito Control Agents."

36 Chris E. Boxmeyer, Sarah Leach, and Susan M. Palchick, "Degradation of Altosid XR Briquets Under Field Conditions in Minnesota," *Journal of the American Mosquito Control Association* 13 (1997): 275-277.

37 Rodger Doyle, "Amphibians at Risk," *Scientific American* (August 1998): 27; Jocelyn Kaiser, "Deformed Frogs Leap Into Spotlight at Health Workshop," *Science* 278 (December 19, 1997): 2051-2052; Minnesota Pollution Control Agency web site at <http://www.pca.state.mn.us>; U. S. Geological Service and the North American Reporting Center for Amphibian Malformities web site at <http://www.npwrc.usgs.gov/narcam>.

one of the chemicals that can result when methoprene breaks down is similar to a natural biochemical called a retinoid or retinoic acid, found in many species.[38] Frogs and other organisms exposed to too much retinoic acid in laboratory settings can have developmental defects.

Research on methoprene in mosquito control has generally not looked at the breakdown products, except as they incidentally occur in the research situation. As discussed earlier, one local experiment showed that frog eggs and tadpoles exposed to high concentrations of methoprene in the laboratory did not have developmental defects.[39] One researcher asserts that, although retinoic acid can be produced from methoprene in a laboratory using a high level of ultraviolet light, it is unlikely to happen in the environment, where methoprene usually breaks down to other chemicals.[40] No one has demonstrated that when methoprene breaks down in the environment where it is applied for mosquito control that it produces enough retinoic acid to harm any species.

There appears to be no correlation between the locations of deformed frogs and methoprene use.

We reviewed dates and locations of reported deformed frogs in Minnesota. Reports of deformed and normal frogs are available to the public along with other information on deformed frogs on an Internet web site of the North American Amphibian Reporting Center for Amphibian Malformations, which is maintained by the U.S. Geologic Survey.[41] This web site shows reports of deformed frogs from counties throughout Minnesota, suggesting that there is not a correlation at the county level between methoprene used for mosquito control and sightings of deformed frogs in Minnesota. Moreover, there were several reports from 1965 of deformed frogs in Washington County, yet methoprene was not discovered until 1968. If methoprene is related to frog deformities, it is clearly not the only cause. To date, however, there has not been a systematic accounting of frog deformities that would permit scientists to assess whether there truly are more frog deformities now than in the past, or whether there is an emerging trend.[42]

ADULT MOSQUITO INSECTICIDES

In addition to larval control, MMCD controls adult mosquitoes in parks, at public events, in residential neighborhoods, and where disease carrying mosquitoes are found. MMCD uses two synthetic pyrethroid insecticides, resmethrin and permethrin, in adult mosquito control. These are known as broad-spectrum

38 Margaret A. Harmon, Marcus F. Boehm, Richard A. Heymann, and David J. Mangelsdorf, "Activation of Mammalian Retinoid X Receptors by the Insect Growth Regulator Methoprene," *Proceedings of the National Academy of Sciences of the United States* 92 (June 20, 1995): 6157-6160.

39 Scientific Peer Review Panel, "An Assessment," 10.

40 David Sullivan, "Methoprene and Frogs," *American Mosquito Control Association (AMCA) Newsletter*, November 1997: 11-12.

41 <http://www.npsc.nbs.gov/narcam>.

42 As part of a dissertation research project, researchers from the Natural Resources Research Institute at the University of Minnesota Duluth conducted one census of frog populations in the Wright County experimental wetlands during the summer of 1998. Frogs were collected from sites treated with *Bti* and methoprene and untreated sites. The project also included examination of frogs from sites in two other states.

insecticides because they kill many types of insects in addition to mosquitoes. Pyrethroids mimic the structure of pyrethrins, a natural botanical insecticide found in chrysanthemum flowers. This similarity does not relate to the toxicity and persistence of synthetic pyrethroids however.

Resmethrin

Resmethrin kills insects by paralyzing their nervous system; it can also kill insects that ingest it and larvae on contact. Resmethrin is registered for use by EPA and sold under various trade names.[43] Commercial formulations usually include other chemicals to enhance effectiveness against a wide variety of agricultural and household pests. Resmethrin is sold under the brand names Raid Flying Insect Killer and Ortho Outdoor Flying Insect Fogger, among other products. Resmethrin is also used to protect stored grain from insects. EPA classifies resmethrin as a restricted use pesticide because of its adverse effects on aquatic organisms. Only certified applicators may purchase and use restricted use pesticides for community mosquito control at aquatic sites because resmethrin is toxic to fish, but anyone can purchase resmethrin products designed and labeled for household uses.

For mosquito control, MMCD uses a product which is a mixture of resmethrin and piperonyl butoxide. Resmethrin is used to kill mosquitoes when they fly, usually at dusk or in early morning hours, when mosquitoes are most active. Piperonyl butoxide, an active ingredient in resmethrin, acts as an insecticide synergist when combined with resmethrin. It enhances the effectiveness of resmethrin by blocking detoxifying enzymes in mosquitoes. Resmethrin breaks down quickly in ultraviolet light; about half of it is gone in 15 minutes.[44]

Resmethrin is a restricted use pesticide because it is highly toxic to fish if improperly used.

Resmethrin is highly toxic to fish and bees, and it is moderately toxic to humans by ingestion and slightly toxic through the skin. It is slightly toxic to birds.[45] It has not caused birth defects or cancers in animal studies, but EPA has not evaluated resmethrin for evidence of human carcinogenic potential.[46] EPA has established a tolerance for resmethrin in food.[47]

An international panel of experts affiliated with the World Health Organization reviewed the scientific literature on resmethrin.[48]

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43 Extension Toxicology Network (EXTOXNET), "Resmethrin," revised 9/93, Pesticide Management Education Program, Cornell University, Ithaca NY, <http://pmep.cce.cornell.edu/>.

44 *Ibid*., 3.

45 *Ibid*., 2, 3.

46 *Ibid*., 2; Environmental Protection Agency, "IRIS Substance File: Resmethrin," March 1, 1997.

47 40 *Code of Federal Regulations* sec. 185.5300, revised July 1, 1997.

48 World Health Organization, "Environmental Health Criteria 92: Resmethrins — Resmethrin, Bioresmethrin, Cismethrin," Geneva, 1989, 57. Published under the joint sponsorship of the United Nations Environment Programme, the International Labor Organisation, and WHO. This report also concluded that resmethrin's degradation products are unlikely to reach levels of environmental significance.

- **The World Health Organization concluded that resmethrins were unlikely to present a hazard to the general public or attain levels of environmental significance when used under recommended conditions and rates for household and other public health use.**

In 1993, the Department of Health conducted a risk assessment of the adult insecticides used by the District.

In 1993, the Minnesota Department of Health (MDH) assessed the risks to humans of the insecticides that contain resmethrin and permethrin (discussed below) as used by MMCD for adult mosquito control.

- **The Minnesota Department of Health risk assessment concluded that "exposure to Scourge [resmethrin] or Punt 57-OS [permethrin] through ingestion or skin contact does not pose a health risk to humans under the scenarios described . . . Brief inhalation of the pesticides should not pose a health risk. Nevertheless, children should be prevented from having prolonged inhalation exposure to the pesticides."**

MDH advised, for example, that children should not be permitted to follow the pesticide applicators as they work.[49] The risk assessment assumed worst-case scenarios for exposure to the insecticides and included a wide margin of safety for people who might be sensitive to the chemicals. Other assumptions included that MMCD treats parks, recreation areas, and residences, and areas within a quarter mile radius of those sites, and that high-use parks were treated a maximum of five times per summer at ten-day intervals. The assessment considered risks by accidental ingestion, inhalation, and skin contact for the insecticides; by accidental inhalation and ingestion for piperonyl butoxide; and by inhalation for oil solvents.[50]

Piperonyl Butoxide

Piperonyl butoxide (PBO) is added to resmethrin in mosquito control applications to make insects more sensitive to the effects of resmethrin. Recent scientific studies done in Japan have shown that PBO can cause liver cancer in mice and rats.[51] This has raised concerns about whether PBO should continue to be used in insecticides and have a tolerance in food.[52] The Japanese research, however,

49 In the risk assessment, the Department of Health estimated a safe level of inhalation exposure. The risk assessment reflects an estimated air concentration of resmethrin that could be safely inhaled for up to four hours. It reflects an estimated air concentration of permethrin that could be safely inhaled for up to six hours. Because of a lack of data, it was not possible to calculate a safe 30 minute exposure level for either resmethrin or permethrin. The air concentration of resmethrin and permethrin that could be safely inhaled for only 30 minutes may be greater than the four or six hour concentrations. (Minnesota Department of Health, "Risk Assessment on Scourge and Punt Materials Used by the Metropolitan Mosquito Control District for the Control of Adult Mosquitoes," March 17, 1993: 21-22, 25, 39-40, 41.)

50 Minnesota Department of Health, "Risk Assessment," March 17, 1993.

51 O. Takahashi, S. Oishi, T. Fujitani, T. Tanaka, and M. Yoneyam, "Chronic Toxicity Studies of Piperonyl Butoxide in F344 Rats: Induction of Hepatocellular Carcinoma," *Fundamental and Applied Toxicology* 22 (1994): 293-303; O. Takahashi, S. Oishi, T. Fujitani, T. Tanaka, and M. Yoneyama, "Chronic Toxicity Studies of Piperonyl Butoxide in CD-1 Mice: Induction of Hepatocellular Carcinoma," *Toxicolog*y 124 (1997): 95-103.

52 40 *Code of Federal Regulations* sec. 185.4900, revised July 1, 1997.

found that before safety would be an issue, people would have to consume about 18,000 times the amount of PBO that the Japanese government currently allows daily in food products.

EPA's registration of PBO had been based on research showing no cancer causing effects, but in 1995 EPA reviewed the research and concluded that PBO should be classified as a possible human carcinogen.[53] So far, EPA's classification of PBO as a Group C carcinogen risk has not resulted in any restriction of use. The Minnesota Department of Health 1993 risk assessment included piperonyl butoxide. PBO was only evaluated for oral and inhalation exposure. The conclusions of the risk assessment summarized earlier also apply to PBO.

Permethrin

Permethrin and piperonyl butoxide, an active ingredient in resmethrin, are classified by EPA as possible human carcinogens.

Permethrin, a synthetic pyrethroid, is sold to the public in various commercial pesticide products. Trade names include Permethrin 57% OS and Pounce (for mosquito control), Duranon Tick and Insect Repellent, Permethrin Tick and Flea Killer for Dogs, and Spectracide Lawn and Garden Insect Control. Permethrin is the active ingredient in RID shampoo for head lice. As with resmethrin, it kills insects by paralyzing their nervous systems.

In mosquito control, permethrin is mixed with mineral oil and soybean oil and sprayed on leaves of bushes and plants where mosquitoes rest or hide during the day. Unlike resmethrin, permethrin is moderately long-acting; on foliage, it can take up to about ten days for half to be broken down.[54] According to the EPA label, it may provide control for up to 14 days in shaded woodland areas. Results of MMCD research found that control of mosquitoes that come in contact with treated foliage is significant for up to five days.[55]

The EPA label of the product used by MMCD states that permethrin is extremely toxic to fish and aquatic organisms and may not be applied directly to water. Because runoff into water may also be hazardous, it should not be applied with 100 feet of lakes and streams. The label also states that it is hazardous to bees and should not be applied where it can get onto blooming crops or weeds while bees are active in the treatment area. It should not be used on crops for food, forage, or pasture. The label specifies droplet size for fogging operations, depending on flow rate and vehicle speed when sprayed from a moving truck.

Permethrin has low toxicity to mammals, but contact with eyes, skin, or clothing should be avoided, and breathing of mist or vapors also should be avoided. Exposure to permethrin may sometimes cause a numbing, tingling, or burning

53 John Doherty, Ph.D. and Esther Rinde, Ph.D., Environmental Protection Agency, Office of Pesticide Programs, to Richard Keigwin and Alan Dixon/Bruce Sidwell, *Carcinogenicity Peer Review of Piperonyl Butoxide*, February 15, 1995, memorandum.

54 National Pesticide Telecommunication Network, "Permethrin," Oregon State University, September 1997, <http://ace.orst.edu/info/nptn/factsheets/perm7.htm>. The typical half life of permethrin in soil is 30 days.

55 Metropolitan Mosquito Control District, "1991 PUNT Residual Study," unpublished, 1992.

sensation that goes away within 12 hours. It is quickly metabolized (broken down) by humans and other animals.[56]

EPA has classified permethrin as a possible human carcinogen.[57] There was no evidence of cancer in long-term studies that fed large quantities of permethrin to rats, but a long-term feeding study of mice showed a slight increase in lung tumors among male mice. Permethrin in not toxic to birds except at very high doses. It is rapidly broken down by micro-organisms in the soil, so it will not contaminate groundwater. It is not harmful to most plants. EPA has set a tolerance for permethrin in agricultural products.[58]

When used as recommended, resmethrin and permethrin are unlikely to pose a hazard to the general public.

An international panel of experts affiliated with the World Health Organization reviewed the scientific literature on permethrin.

- **The World Health Organization concluded that permethrin and its degradation products were unlikely to attain levels of environmental significance when recommended application rates were used.**

There is also no evidence of adverse effects on people when permethrin is used as recommended. The panel also noted that, although permethrin is highly toxic to fish, aquatic arthropods, and honey bees under laboratory conditions, lasting adverse effects are unlikely when the chemical is used as recommended in the field.[59] In addition, previously cited findings from the Minnesota Department of Health's risk assessment also apply to permethrin.

INSECTICIDES USED BY OTHER JURISDICTIONS

We asked what insecticides were used in Minnesota cities outside the Twin Cities area and other states to control mosquitoes. As we discussed in Chapter 1, between 40 and 44 Minnesota cities provided mosquito control services in 1997 and 1998. Using information from the municipal pest control applications filed with the Department of Agriculture, we found that:

- **For adult mosquito control, most of the acres in outstate cities were treated with chlorpyrifos, a broad spectrum organophosphate. Permethrin was the next most used insecticide.**

These Minnesota cities treated about 42,000 acres with insecticides to control adult mosquitoes in 1997 and 1998. They used products containing chlorpyrifos to treat about 33 percent of these acres in 1997 and 40 percent in 1998.

56 National Pesticide Telecommunication Network, *Permethrin*.

57 *Ibid.*

58 40 *Code of Federal Regulations* 180.378, revised July 1, 1997.

59 World Health Organization, "Environmental Health Criteria 94-Permethrin," Geneva, 1990, 16-17. Published under the joint sponsorship of the United Nations Environment Programme, the International Labor Organisation, and WHO.

Permethrin was the second most commonly used insecticide accounting for 28 percent of the acres treated in 1997 and 21 percent in 1998.

Few cities in Minnesota outside of the Twin Cities area attempt to control mosquito larvae; these cities only treated about 5,000 acres in 1997 and 1998. Over 60 percent of larval control was done using methoprene, primarily pellets.

Generally, we found that:

- **While most states used the same insecticides as MMCD, some states also used other insecticides that can potentially cause more harm to the environment because they are less specific to mosquitoes.**

The most commonly used insecticides in the four state-operated mosquito control programs (Connecticut, Delaware, Kentucky, and Maryland) were *Bti*, methoprene, resmethrin, and permethrin.[60] In addition, each of these states used various organophosphates, such as chlorpyrifos, naled, temephos, and malathion. Organophosphates are non-systematic, broad-spectrum insecticides of the type that MMCD stopped using in the mid-1980s. Kentucky also used carbaryl (trade name Sevin), a broad-spectrum carbamate insecticide to control adult mosquitoes. Carbaryl can produce adverse effects in humans and animals and is lethal to many nontarget species.[61]

Insecticides used in six other states with large mosquito control operations included the same insecticides as MMCD currently uses, in addition to malathion (used in all but one of these states), naled (Dibrom), and chlorpyrifos.[62] Mosquito control districts in California also used propoxur (Baygon), which is a general use carbamate insecticide. Florida and North Carolina also used sumithrin, a synthetic pyrethroid which is commonly combined with PBO, to kill adult mosquitoes. A mosquito larvae insecticide commonly used in other states is temephos (Abate), which is a broader spectrum insecticide than *Bti* or methoprene.[63] Finally, some states also used natural pyrethrins and oils on the surface of water to control mosquito larvae.[64]

ALTERNATIVES

Lagenidium giganteum, a fungus that attacks mosquito larvae, is a new insecticide that shows promise as an improvement over current larvicides. It is considered a biological insecticide. MMCD is testing Laginex, a commercial form of *Lagenidium giganteum*, as an alternative to methoprene to control cattail mosquito

60 The results of our telephone survey in other states are discussed in Chapter 5.

61 EXTOXNET, "Carbaryl," revised 6/96, 1.

62 Program Evaluation Division telephone survey of other states, Summer 1998. These states include: California, Florida, Massachusetts, New Jersey, North Carolina, and Rhode Island.

63 EXTOXNET, "Temephos," revised 3/98. In addition to Delaware, Florida and New Jersey used temephos.

64 Florida, California, and Rhode Island continue to oil some surface waters.

larvae.[65] Laginex is about half the cost of methoprene and may pose fewer risks to other insects. One limitation is that Laginex has a shelf life of only two weeks, requiring precise timing when ordering and applying the product. Unlike *Bti*, it can reproduce itself in the environment, so it has some potential for killing successive broods of mosquitoes.

Laginex is a new larval insecticide being tested by the District.

Researchers have tested *Lagenidium giganteum*'s safety for a variety of organisms, including green plants, algae, nontarget insects, fish, crayfish, crustaceans, mallards, and quail.[66] One species of biting gnat was adversely affected. Based on laboratory tests, researchers have reported some possibly harmful effects to a few types of small water crustaceans and one type of midge at higher doses. The researchers stated, however, that their results cannot be generalized to natural systems where the fungus would be used for mosquito control.[67] Growth of the fungus is significantly restricted above 90 degrees (F), which precludes active infection of either birds or mammals because of their higher body temperatures. Intravenous tests in mice showed their ability to clear the fungus after 18 hours. Treated animals showed no abnormal behavior or appearance.[68]

As to the value of natural predators for mosquito control, we found that:

- **There is no scientific evidence that natural predators, such as bats and purple martins, can control mosquitoes to the degree demanded by people.**

Purple martins and bats consume relatively few mosquitoes.[69] Dietary studies have shown that mosquitoes are insignificant in the purple martin diet; studies of stomach contents of bats showed beetles as the dominant food.[70]

Another review of natural predators, including dragonflies, praying mantis, purple martins, and bats, concluded that these organisms have not significantly reduced mosquito populations in controlled experiments, particularly during mosquito

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65 Stephen Manweiler, Mark Smith, Scott Luberda, and Gary Hillsdale, "Laginex AS Test in a Minnesota Cattail Marsh, June-July 1997," unpublished, Metropolitan Mosquito Control District, nd.

66 James L. Kerwin, Deborah A. Dritz, and Robert K. Washino, "Nonmammalian Safety Tests for *Lagenidium giganteum* (*Oomycetes: Lagenidiales*)," *Journal of Economic Entomology* 81 (1988): 158-171.

67 Lori B. Nestrud and Richard L. Anderson, "Aquatic Safety of *Lagenidium giganteum:* Effects on Freshwater Fish and Invertebrates," *Journal of Invertebrate Pathology* 64 (1994): 228-233.

68 James L. Kerwin, Deborah A. Dritz, and Robert K. Washino, "Confirmation of the Safety of *Lagenidium giganteum* (*Oomycetes: Lagenidiales*) to Mammals," *Journal of Economic Entomology* 90 (1990): 374-376.

69 Mitchell Lee, "Myths About Mosquito Control (Bats, Birds and Bug Zappers)," *The Vector Control Bulletin of the North Central States* 2 (1993): 35-40; Gary L. Benzon, "Controlling Mosquitoes and Other Flying Insects Within Municipalities," *Public Works* (December 1988): 46-49.

70 William F. Lyon, Richard L. Berry, and Michael F. Collart, "Mosquitoes—Ohio State University Extension Factsheet," Department of Entomology, Columbus OH.

population peaks.[71] One reason is that mosquitoes are often found in habitats that are not suited to these generalist predators. Furthermore, the enormous production of nuisance mosquitoes following a rain can overwhelm predators.

In some parts of the country a fish called a mosquitofish, or *Gambusia*, is used to control mosquitoes. The fish can be put into ponds to eat mosquito larvae, but the fish also eats nontarget insects. The fish is found in southern Illinois and in the Mississippi River only as far north as central Iowa, which suggests that Minnesota maybe too far north for it to survive here.[72] If the fish were introduced in Minnesota, it might disrupt native species. DNR does not support introduction of this fish.[73]

SUMMARY

In this chapter, we reviewed studies on the safety of the insecticides that MMCD uses for larval and adult mosquito control. We reviewed EPA documents, scientific research, and risk assessments.

Overall, we found little evidence that *Bti* or methoprene, which are used to kill mosquito larvae, pose a significant risk to the environment or to humans; the same applies to *Bti* when used against black fly larvae. Some species of midges may suffer decreases in population where these insecticides are used. Researchers have not detected significant adverse effects on other aquatic organisms, the reproduction of red-winged blackbirds, or the numbers of other bird species. We also reviewed current thinking on the possible relationship between deformed frogs and methoprene. To date, scientists have not been able to find a cause for the deformities. A by-product of methoprene's breakdown can cause deformities in the laboratory, but there is no credible evidence that this actually happens in the field.

As to the insecticides used against adult mosquitoes, the Environmental Protection Agency, the World Health Organization, and the Minnesota Department of Health have found that resmethrin and permethrin should not pose hazards to the public when applied in the prescribed manner. However, permethrin and resmethrin are broader spectrum insecticides and permethrin and piperonyl butoxide, an active ingredient in resmethrin, are possible human carcinogens. Therefore, these products must be applied judiciously and in strict conformity with EPA label requirements.

We also reviewed the use of alternatives to control mosquitoes. Natural predators against mosquitoes, such as bats and purple martins, have not been effective at controlling mosquitoes to the degree that people want.

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71 Illinois Department of Public Health, "Mosquitoes in Illinois—Recommendations for Prevention and Control," 1995: 4.

72 <http://www.state.ia.us/fish/iafish/miscfam/mosquito.htm>.

73 Minnesota Environmental Quality Board, Mosquito Control Technical Work Group, "Final Report," April 12, 1994: Appendix D.