The Mosquito Abatement Program in Teton County

by

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Introduction

Few topics have polarized residents of Teton County like the issue of mosquito abatement. On one side are those who believe that mosquitoes should be controlled by any effective means available to protect residents, tourists, and livestock from annoyance and disease. On the other side are those who consider mosquitoes an indispensable component of the food web and believe that eradication by chemical treatment is unsafe to people and the environment. This paper will explore the history of mosquito abatement in the county and possible directions for its future, presenting information from both sides of the mosquito abatement controversy. It is my goal, and the goal of the Jackson Hole Alliance for Responsible Planning, to present unbiased information as clearly as possible, so the public may make sound, informed choices regarding the future of mosquito abatement in Teton County.

Mosquitoes in Teton County

Throughout the state, mosquitoes annoy people and plague livestock. They carry diseases that can infect humans and cause weight loss, decreased milk production, and reproductive problems in cattle (Univ. of Wyoming 1985). To date, 42 species of mosquitoes have been identified in Wyoming (Denke and Spackman 1990). The most common species belong to the Culex, Anopheles, Aedes, and Culiseta genera. In a survey presently being conducted by Teton County Weed and Pest District (TCWPD) personnel, Culex has not yet been found in Teton County. According to Fred Lamming, director of Teton County's mosquito abatement program, about 15 mosquito species inhabit the Jackson Hole area. Of these, only four or five are most bothersome to humans (Fred Lamming, personal communication), but they can be present in enormous numbers.

A recent Jackson Hole Guide article (Simmons 1997) quoted Teton County Sheriff and Jackson Hole native Roger Millward: "I can remember going fishing down at Flat Creek [prior to the mosquito abatement program] and you'd breathe them in every time you took a breath."

Long-time valley resident Lyle McReynolds (pers. comm.) also described inhaling mosquitoes in the early seventies, especially in areas along the Teton Village Road, and remembered that the infestations lasted throughout the summer. Grand Teton National Park employee Ed Trigg said the National Elk Refuge irrigated the Kelly Hayfields during that time, and the water backed up along Blacktail Butte. He recalled mowing grass along Mormon Row amidst dark clouds of swarming, biting mosquitoes (pers. comm.). Cal Mathieu estimated that since the mosquito abatement program began, mosquito numbers are only about 10 to 15 per cent what they used to be (pers. comm.).

On the other hand, Eleanor Onyon (pers. comm.) described the valley's mosquitoes in the late sixties as "bad, but not impossible. You'd put on repellent and go out- like you do now when you go up to the park or to the Winds." She said the mosquitoes diminished as the summer progressed and the land dried out.

In 1974, only five people responded to a survey on mosquito control conducted by the Jackson Hole Guide. Of the five, three were in favor of control and two opposed. In a November 12, 1974 letter to the editor, Gene Young, then Supervisor of the TCWPD, wrote, "...due to the lack of interest, mosquito control will not be very high on the list of necessary projects."

The issue was not dead, however. TCWPD files contain letters written in 1976 by citizens concerned about mosquito problems in the county. Quotes from two of these letters follow:

> "...The mosquito is a severe loss to owners of livestock in the valley as well as to the entire tourist industry upon which so many of us depend. Further, the mosquito deprives all of our citizens of about 1/3 of our short but beautiful summer by preventing the enjoyment of almost all outdoor activities." (J.E. LaRue, Shootin' Iron Realty, 1/29/76)
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> "Recently we have recognized a significant increase in the number of cases of Equine Infectious Anemia in and around Teton County... Biting insects [flies and mosquitoes] are considered to be the main mode of natural dissemination and transmission of the disease." (K.J. Griggs, D.V.M., 2/11/76)

In late February of 1976, an article in the Jackson Hole News stated that the mosquito had been officially declared a pest by the TCWPD. In making the declaration, the District considered the opinions of horse owners worried about equine infectious anemia, motel owners who claimed that mosquitoes kept summer tourists away, and doctors concerned about encephalitis. Because TCWPD funds can only be used on declared pests (Fred Lamming, pers. comm.), the mosquito must be redeclared as a pest each year.

Mosquitoes as Disease Vectors

Concerns about disease transmission play a major role in the mosquito abatement controversy. Mosquitoes are known vectors of a number of disease-causing viruses throughout the world, including the pathogens responsible for encephalitis, equine infectious anemia, malaria, yellow fever, dengue, filariasis, and dog heartworm (U.S. Dept. of Health and Human Services 1977). In the seventies, a viral hepatitis outbreak in New Jersey was linked to local mosquitoes found to be carrying hepatitis B antigen (Dick et al. 1974). Contrary to media hype, however, it is physiologically and mechanically impossible for mosquitoes to transmit the human immunodeficiency virus (HIV) that causes AIDS (Crans 1992).

Malaria, yellow fever, dengue, and filariasis occur mainly in tropical and subtropical regions (U.S. Dept. of Health and Human Services 1977). Miller (1996) states that there were seven cases of malaria reported to the Wyoming Department of Health in 1996, but because there are no known mosquito vectors of malaria in the state, it is believed that the cases were acquired elsewhere.

According to local veterinarian Kenneth Griggs (pers. comm.), horses diagnosed with equine infectious anemia are usually slaughtered to prevent the disease from spreading. Dr. Lyn Woodard (Director, Wyoming State Veterinary Laboratory, pers. comm.) reported that equine infectious anemia is now rare in the state, averaging one or two cases per year. Over the last ten years, only three or four cases of dog heartworm have been reported to the State Veterinary Lab, all from the Casper and Gillette areas.

Of all the mosquito-borne diseases, encephalitis is of greatest concern in the United States. Encephalitis affects the central nervous system and is caused by a group of pathogens called arboviruses, which are usually transmitted to people by mosquitoes (U.S. Department of Health and Human Services 1977). Five major types of arboviral encephalitis occur in the United States: eastern equine encephalitis, western equine encephalitis, St. Louis encephalitis, California group encephalitis, and Venezuelan equine encephalitis. Viruses that cause these diseases normally infect birds or small mammals, with occasional infections of humans or horses which can cause severe illness or death.

Schmidtmann (1996) presented a summary of encephalitis cases occurring throughout the United States in 1995. Three states (Texas, Illinois, and Louisiana) reported 22 cases of human St. Louis encephalitis, with one fatality. Four human cases of eastern equine encephalitis, one fatal, occurred in eastern and midwestern states, and 84 horses were diagnosed with the disease from Michigan to South Carolina and along the Gulf Coast to Texas. The nation averages five human cases of eastern equine encephalitis per year. There were 72 reported human cases of California group encephalitis, mostly in the upper midwest and West Virginia.

No cases of human western equine encephalitis (WEE) occurred in the United States in 1995, but one horse infection was reported (Schmidtmann 1996). Scientists detected high levels of WEE virus activity in eastern Wyoming's Platte and Goshen Counties where scientists isolated the virus from pools of mosquitoes. The Wyoming Department of Health, however, stated that there is no cause for alarm as these results may represent normal virus activity (Klietz and Miller 1995). Furthermore, Culex tarsalis, the principal mosquito vector of WEE, prefers to feed on birds rather than horses or people (Brewer 1995). Compared to eastern equine encephalitis which has a 50% human mortality rate (Fealey 1995), WEE has a mortality rate of only three or four percent, but it can cause damage to the central nervous system, particularly in children and elderly people (Brewer 1995).

In 1996, there were no reported cases of encephalitis in Wyoming (Miller 1996). Cheryl Corvin of the Epidemiologist's Office of the Wyoming State Department of Health recently searched records from 1991 through the present and found no cases of encephalitis occurring in northwestern Wyoming (pers. comm.). In the late seventies, a Wilson resident contracted encephalitis, but Jackson physician James Little (pers. comm.) clarified that this case was not mosquito-borne.

A recent newspaper article (Simmons 1997) stated that a case of equine encephalitis had been reported in Sublette County, but neither Dr. Woodard of the State Veterinary Lab nor Sublette County Health

Officer Tom Johnston (pers. comm.) was aware of it. Dr. Johnston did state that a case of equine infectious anemia had occurred in the county during the past three years. According to Dr. Woodard, of greater concern than encephalitis in Wyoming is vesicular stomatitis, an insect-transmitted disease of cattle. Veterinary professionals still do not have a clear understanding of the epidemiology of this disease.

Teton County's climate may limit the potential for disease outbreaks here, as our short mosquito season prevents the development of large populations of vector species. According to Denke and Spackman (1990), disease transmission in Wyoming is of some concern, but the primary mosquito problem is annoyance to people and livestock, which leads to economic losses in high-tourism areas. Local infectious disease specialist Dr. Shannon Harrison concurred that, although mosquitoes are bothersome in Teton County, a mosquito-borne disease outbreak is unlikely here due to the climate and altitude (pers. comm.).

The Biology and Behavior of the Mosquito

Mosquitoes occupy a valuable niche in the natural world. They provide food for other organisms such as fish, birds, bats, amphibians, and spiders, and spread diseases that control animal populations (Fealey 1995).

After hatching from eggs, mosquito larvae pass through several stages before they become adults (Borror and DeLong 1964; Zoecon 1993a). The emerging larvae, also called wrigglers, are aquatic. Larvae of most species feed on algae and organic debris. Over a period of three days to two weeks, the larvae grow and progress through a series of molts where they shed their exoskeletons. The phases between successive molts are called instars; the first instar begins at hatching and ends with the first molt.

Mosquito larvae pass through five instars and four molts before entering the pupal stage, a resting, non-feeding phase during which larval systems break down to be replaced by adult systems. Also aquatic, pupae are called tumblers because they tumble about in the water. Depending on weather, the pupal stage can last from one day to a few weeks.

The non-aquatic adult then emerges from the pupal stage ready to fly and search for a mate. Adult males survive only about a week after breeding, while females can live up to five months. Both sexes feed on flower nectar, but only females bite and draw blood from people and animals to obtain nourishment for egg-laying. Females are capable of flying up to 20 miles from their larval habitat in search of food (Denke and Spackman 1990), but Fred Lamming stated that most mosquitoes probably rarely travel more than half a mile (pers. comm.).

The most abundant Wyoming mosquito genus, Aedes, breeds in areas that periodically flood (University of Wyoming 1985). Females of this genus lay eggs on soil near water, but the eggs do not hatch until they are flooded by water. Aedes mosquitoes thrive where water levels fluctuate and where they are protected from wave action, but they cannot survive in running water, or the deep open water of lakes and ponds. This genus overwinters in the egg stage (Denke and Spackman 1990).

Members of the Anopheles, Culex, and Culiseta genera lay eggs on the surface of water. They produce several generations each summer in permanent pools of standing water, ponds and puddles, treeholes, or open containers. Eggs hatch in one to three days (Zoecon 1993a). Inseminated females of these species overwinter in protected areas.

According to Denke and Spackman (1990), the major source of mosquito habitat in Wyoming is probably irrigation systems, which distribute water by flooding fields and pastures. This method can create prime breeding areas for mosquitoes by trapping water in low-lying areas to form permanent pools.

In Teton County, adult mosquitoes typically emerge first in Buffalo Valley, then in the Poker Flats and Teton Village areas, and finally in Jackson (Simmons 1997). Time of emergence varies with mosquito species (Fred Lamming, pers. comm.).

Control of Mosquitoes in Teton County

Mosquito control efforts in Teton County target insects either in the larval stage with compounds called larvicides, or in the adult stage with adulticides. Larvicides, which kill the insects before they develop into biting, breeding adults, are generally more effective than adulticides because the larvae are confined to easily-located bodies of water, whereas the airborne, mobile adults are harder to find.

The larviciding process, however, is more labor-intensive and time-consuming because larval development must be closely monitored to determine the best time to apply the compound for maximum effectiveness. As recommended by the University of Wyoming Agricultural Extension Service (1985), TCWPD personnel first identify mosquito breeding sites throughout the county, then travel to each to perform dip counts which indicate the growth stages of the mosquito larvae present. Larvae in the first to fourth instar stages are most susceptible to larvicide treatment (Teton County 1990). Twenty-five areas in Teton County have been identified as breeding areas for mosquitoes (Table 1) (Lamming et al. 1996).

Larvicide treatments used in Teton County include the bacterium *Bacillus thuringiensis* var. *israelensis* (B.t.i.) and the insect growth regulator, methoprene. B.t.i. is marketed by Abbott Laboratories under the brand name VectoBac and by Biochem Products as Bactimos. Methoprene, marketed as Altosid by the Zoecon Corporation, was used in the county from 1979 to 1989 with questionable success (Teton County 1991). According to Don Barney, former administrator of the Teton County mosquito abatement program, liquid Altosid SR-10 was mixed with silica sand and sprayed aerially during this time over wet areas. For optimal effectiveness, however, the plane had to fly only 30 feet above the water. Because of the potential danger to the pilot, the liquid spraying was discontinued. Bactimos was introduced in 1989 by the Citizens

Table 1. Identified mosquito breeding areas in Teton County (Lamming et al. 1996).

Area 1	Buffalo Valley- Highway 26, Buffalo Valley Road, Turpin Meadows, Fir Creek
Area 2	North of Jackson- R Lazy S, JY Ranch
Area 3	Gros Ventre/Kelly/North of Fish Hatchery
Area 4	Meadow Road/King's Highway, Moulton Loop, Owl Creek, JH Golf Course
Area 5	King's Highway to Highway 22
Area 6	Teton Village Road, Lake Creek Subdivision
Area 7	Fish Creek Road
Area 8	Teton Pass, Trail Creek, V. Huidekoper
Area 9	Fall Creek Road/Wilson, Fall Creek Ranch
Area 10	Boyles Hill Road
Area 11	Ely Springs
Area 12	South Park Loop
Areas 13, 14	Cottonwood Park and High School Road
Area 15	Highway 89 south of Jackson
Area 16	Rafter J
Area 17	Game Creek
Area 18	Munger Mountain/Evans Road
Area 19	Hoback Junction to Dog Creek
Area 20	Highway 189/191
Area 21	Town of Jackson
Area 22	Highway 22
Area 23	Swinging Bridge to Highway 89
Area 24	Alta
Area 25	Pacific Creek Subdivision

Review Committee and has been used ever since. TCWPD supplies Bactimos briquets or VectoBac granules and training for their application to county landowners free of charge.

Adulticide treatments are aimed at mosquitoes that have metamorphosed to adults and migrated from their watery breeding sites. Since the mid-seventies, Teton County has conducted aerial spraying of the organophosphate adulticide malathion. To determine when the spraying should begin in a season, the TCWPD researchers use light traps to count mosquitoes and identify what species are present (Hudelson and Grant 1990, Hayden 1996).

According to a Jackson Hole News article (1975), spraying of adult mosquitoes was initiated by the Jackson Hotel and Motel Association in 1974, after association members claimed that mosquito infestations were causing room cancellations. County funds were not used for the program until 1977, after the mosquito was officially declared a pest by the TCWPD. Table 2 summarizes amounts of larvicide and adulticide used in the county since 1977.

In 1997, Teton County allotted $90,000 from the general budget for use in the mosquito abatement program for costs such as personnel, aircraft contracting, equipment, biorational controls, and chemicals. Science and research funding comes from separate TCWPD funds. Mosquito abatement funds are used only for treatments on private and county lands, including subdivisions, ranches, and town properties. No mosquito control presently occurs on public lands in the county, including the Bridger-Teton National Forest, Grand Teton National Park, and the National Elk Refuge. There is some control on private camps within National Forest boundaries, but the landowner pays for the treatments.

Larvicide Treatments

Bactimos and VectoBac. Biological control, or **biorational**, methods are becoming more popular throughout the world because of rising costs, concerns about environmental contamination, and increasing insect resistance associated with chemical insecticides. Included in the category of biorational controls are **microbial** insecticides such as B.t.i. Biorational controls, as well as chemical controls, must undergo expensive and rigorous scientific testing to be registered by the EPA for use in the United States.

Initially isolated in 1902 from diseased silkworm larvae, the bacterium *Bacillus thuringiensis* was first used commercially as an insecticide in the United States in 1958. It has since been sprayed over thousands of acres of forest land to suppress populations of insects such as the spruce budworm and gypsy moth (Jenkins 1992). The variety *israelensis* is specific to mosquito and black fly larvae and has been used worldwide for about 15 years (Peairs and Cranshaw 1991, Fealey 1995).

B.t.i., the active ingredient in Bactimos and VectoBac, works by attacking the gut of the larvae. When the bacterium sporulates to reproduce, a protein crystal forms that becomes toxic when it is ingested by mosquito or black fly larvae (Sulaiman et al. 1990). The toxin eats through the gut wall, spilling the contents of the gut into the body cavity and bloodstream. Nerve transmissions

Table 2. Larvicide briquets used and acres sprayed with adulticide in Teton County, 1977 to 1996 (from TCWPD reports 1991-1996).

Year	# Cases Larvicide Briquets[1]	# Acres Sprayed - Adulticide
1977	0	16,500
1978	0	15,000
1979	40 (Altosid)[2]	25,344
1980	40	27,646
1981	40	20,091
1982	40	28,003
1983	54	27,677
1984	52	29,579
1985	74	32,296
1986	71	34,525
1987	31	18,207
1988	78	32,719
1989	81 (Bactimos)	37,027
1990	78	14,540
1991	133	27,820
1992	No data available	No data available
1993	102	26,322
1994	173, 1 tray, 3 bags VectoBac G	20,900
1995	62	29,650
1996	196, 14 trays, 10 bags VectoBac G	39,310

[1]Altosid used 1979-1988, Bactimos used after 1988. 100 briquets per case, 20 per tray, 5 trays per case. One briquet covers 100 square feet of water surface.

[2]Liquid Altosid SR-10 sprayed from low-flying plane in some areas, 1978-1988; sprayed with hand pump sprayer in early 90s.

are eventually interrupted, resulting in paralysis and death, usually within 24 hours (Abbott Laboratories 1996). To be effective, B.t.i. must be consumed by first through fourth instar larvae (Teton County 1991).

Used in briquet form, Bactimos takes about five days to sporulate, then dissolves slowly in the water over a period of 30 days (Fred Lamming, pers. comm.). VectoBac's granular formulation dissolves faster in water and sporulates within two days. VectoBac granules are therefore preferred when larvae are in later stages of development.

B.t.i. formulations have proven highly effective in field trials (Schmidt 1989, Sulaiman et al. 1990, Abbott Laboratories 1996). In 1990, Hudelson and Grant estimated control in Teton County mosquito populations at 98%, exceeding the control achieved with Altosid.

Sinegre et al. (1979) found that B.t.i. had minimal effects on aquatic nontarget organisms such as crustaceans, dragonfly larvae, shrimp, fish, and oysters. According to Abbott Laboratories (1996) and Garcia (1980), B.t.i. has a highly specific mode of action against a narrow host spectrum (mosquito and black fly larvae). At tested field rates, no toxic effects have been demonstrated in mammals, amphibians, fish, crustaceans, nontarget insects, flatworms, earthworms, or mollusks. VectoBac is degraded by aquatic microorganisms and sunlight and has a half-life of less than seven days. According to the manufacturer, no adverse environmental effects have been documented during ten years of commercial use of VectoBac.

<u>Altosid</u>. Called a "soft" chemical insecticide by Peairs and Cranshaw (1991), Altosid consists of the insect growth regulator methoprene, a synthetic hormone that inhibits normal mosquito growth and development. By mimicking the mosquito's juvenile hormone, methoprene disrupts metamorphosis and prevents the pupae from transforming into adults. The pupae eventually die and no adults emerge (Hudelson 1988).

Registered in 1975 as the first and only **biochemical** agent for mosquito control, methoprene was subjected to extensive testing, such as chronic oncogenicity (causing tumors), mutagenicity (causing mutations), and teratogenicity (causing fetal deformities); plant uptake studies, aquatic embryo, larvae, and life cycle studies; and aquatic fate testing. In 1982, the EPA re-registered the product as a **biorational** compound, which requires less stringent testing for registration (Zoecon 1993b).

According to Zoecon (1993b), Altosid has little effect on the food web because it attacks mosquito pupae, which are rarely consumed by vertebrate and invertebrate predators. In mammals and birds, methoprene was found to rapidly degrade by metabolic processes, and acute toxicology studies found no adverse effects at label rates on numerous species of fish, amphibians, and nontarget insects including brown trout, western toad, spotted salamander, southern leopard frog, mayfly, dragonfly, and caddisfly.

Because it is effective only for seven days after application, the use of Altosid requires close attention to larval development. Bactimos briquets last 30 days, but they are not easily applied in areas where water does not disperse the larvicide easily, such as vegetation-choked marshes or heathlike bogs (Teton

County 1991). In the early 90s, TCWPD applied liquid Altosid to these areas with a backpack hand-pump sprayer.

In a study done by the City of Laramie (Whitman 1994), methoprene was found to be "relatively effective". Hudelson (1988) recommended aerial applications of liquid Altosid for large expanses of wet ground, but also reported that the process was expensive and time-consuming.

Adulticide Treatment

When mosquitoes reach peak emergence in the county, a pilot is contracted to spray malathion from a fixed-wing aircraft. Brand names of malathion used include Fyfanon ULV (ultra low volume), manufactured by Cheminova, and Cythion ULV, made by American Cyanamid. The chemical is applied at the rate of 2.8 ounces per acre.

In 1996, 39,310 acres were sprayed in the county. According to Fred Lamming, spraying in the county begins in Buffalo Valley, where mosquitoes first emerge, and then proceeds in a southerly direction through the county (Simmons 1997). Spraying intentions are advertised through public service radio announcements and up-to-date recorded messages on the TCWPD Mosquito Hot-Line (Lamming et al. 1996).

In recent years, many county residents have requested that the plane turn off its sprayer over their property (Testa 1995), but Lamming asserts that an area cannot be treated effectively for mosquitoes if it is only partly sprayed, and that a minimum of ten acres is needed to honor a no-spray request (Lamming, pers.comm.). In 1997, the town of Wilson will not be sprayed, because the number of residents making no-spray requests represented a large enough area to be avoided.

Controversy Surrounding Malathion Use

Debate over the spraying of malathion in the county often stems from concerns about its toxicity. The visibility of the spraying process also fuels controversy. While larvicide treatments are unobtrusive and go unnoticed by the public, spraying a fog of insecticide from a plane is obvious and unsettling to many people. Furthermore, mosquitoes from unsprayed areas readily migrate into sprayed areas, necessitating repeated spray applications throughout the summer.

In addition, the potential for mosquitoes to develop resistance to malathion is high. Malathion has now been sprayed in Teton County for more than 20 years. Throughout the world, insects are developing resistance to pesticides used over long periods of time. For example, the University of Reading (1997) reports that the tobacco budworm has become resistant to all insecticides that have historically been used against it. Fred Lamming recently stated that local mosquitoes have not yet developed resistance to malathion, but it is likely that they will sometime in the future (pers. comm., Hayden 1995).

While malathion can kill natural mosquito predators such as fish, aquatic stages of amphibians, bats, and other insects (Tuttle 1995, Extoxnet 1993a, Ohio State University 1997), mosquitoes can develop resistance and continue to multiply, in what is often called the "pesticide treadmill."

With public pressure and supporting epidemiological data from the Los Angeles County Department of Health Services, California recently stopped malathion spraying to control the Mediterranean fruit fly in Los Angeles, after linking malathion exposure to a number of adverse health impacts (Testa 1994). In these times of heightened environmental awareness, the public is demanding more judicious use of chemical insecticides.

The following review of literature concerning malathion's effects on people, wildlife, plants, and the environment is not meant to be exhaustive. Because of the controversy surrounding chemical insecticides, research results are sometimes conflicting or inconclusive. Wherever possible, I have pointed out misleading statements or discrepancies.

Malathion and People

Also know as carbophos, maldison, and mercaptothion, malathion is a broad-spectrum, general use pesticide effective against sucking and chewing insects such as flies, grasshoppers, mosquitoes, household insects, animal parasites, and body lice (Extoxnet 1993, Smith 1987). Malathion was introduced in the early fifties, and ultra low volume applications were pioneered in the sixties. According to American Cyanamid, malathion has been used successfully throughout the world for over 40 years.

The Occupational Health Guideline for Malathion, produced in 1978 by the U.S. Public Health Service and Centers for Disease Control, reported the following research findings. Malathion can affect the body upon inhalation, skin or eye contact, or ingestion. Repeated exposure, such as by those who apply the pesticide, may increase susceptibility to this and related chemicals. Malathion is a respiratory irritant, and persons with pulmonary impairment may be at increased risk from exposure. This document also stated that malathion is one of the least toxic of the organophosphate insecticides, and that very large exposures are required to cause symptoms.

Inhalation of high concentrations of malathion can produce respiratory and ocular effects such as tightness in the chest, wheezing, laryngeal spasms, constriction of pupils, aching of the eyes, blurring of vision, tearing, and headache. When malathion is ingested, gastrointestinal effects such as nausea, vomiting, appetite loss, abdominal cramps, and diarrhea may appear. Central nervous system effects, or malathion intoxication, may include giddiness, confusion, slurred speech, and loss of muscular coordination.

Effects on the central nervous system are derived from malathion's activity as a cholinesterase inhibitor. Cholinesterase is an enzyme needed for proper functioning of the nervous systems of humans, other vertebrates, and insects (Extoxnet 1993b). The U.S. Department of the Interior (1985), however, cited a study in which an oral dose of 24 milligrams of malathion given daily for more than 14 days was necessary to lower blood cholinesterase activity in adult volunteers, indicating a relatively low acute toxicity in humans. According to the U.S. Dept. of Health and Human Services (1978), malathion is less toxic to humans than most anticholinesterase agents because it is metabolized in the liver to an inactive form.

In susceptible insects, malathion breaks down into its oxygen analog, malaoxon, which is 68 times more toxic than the parent compound, but very transitory (Smith 1987, Testa 1994). According to Hudelson (1988), malathion is not converted to malaoxon in mammals. It is hydrolyzed in the liver instead into non-toxic metabolites which are excreted from the body. However, Testa (1994) reported that malaoxon does affect the nervous system of mammals, including humans, and Gosselin et al. (1984) reported a case of severe cholinesterase inhibition in an infant after exposure to malathion. According to Extoxnet (1993), numerous cases of malathion intoxication have occurred among pesticide workers and small children through accidental exposure.

Some local residents have come forward with claims of sensitivity to malathion. These claims are consistent with research findings indicating that many people experience allergic symptoms from exposure to malathion (U.S.D.I. 1985). Eleanor Onyon of Wilson told of attending a concert in the early seventies at Teton Village while a truck was spraying malathion around nearby buildings. Soon afterward, she developed severely dry, cracked skin. A local physician diagnosed the problem as an allergy to malathion. Thereafter she stayed away during spraying times, but this summer she was accidentally exposed again. She developed swollen, itchy eyes, a purulent infection of one ear, nasal and head congestion, and extremely sensitive facial skin that bled when touched.

Cynthia Craton claimed that she and her daughter have allergy-type symptoms that coincide with spraying of malathion in the Red Top area where they live. They experience swollen eyes, nasal congestion, blocked ears, scratchy throat, and disabling fatigue.

In their recent review of the medical and scientific literature, Sinclair and Pressinger (1997) found links between malathion exposure and human medical conditions such as renal failure, liver damage, leukemia, aplastic anemia, amyoplasia (a birth defect characterized by a lack of skeletal muscle), and even death. Use of pesticides such as malathion in developing countries has been correlated with increasing incidence of respiratory infections, skin disease, ear infections, tuberculosis, and dental caries (Raloff 1996). Also, malathion has produced detectable mutations in human blood and lymph cells (Extoxnet 1993, Sinclair and Pressinger 1997).

Another study found that children born to mothers exposed during pregnancy to aerial spraying of malathion for medflies in California had two and one-half times the incidence of gastrointestinal disorders as those not exposed (Univ. of Southern California 1992). However, American Cyanamide (no date) claimed that studies of live births of mothers exposed to malathion during medfly eradication in California revealed no relationship between the malathion exposure and the occurrence of birth defects, low birth weight, or other anomalies.

An added concern is that malathion used in most aerial spraying programs, including Teton County's, is "technical grade" rather than purified (Testa 1994, Sinclair and Pressinger 1997). Technical grade is approximately 95% pure malathion and 5% other chemicals that are added for spraying. These impure additives can be far more toxic than pure malathion. One impurity, for example, O,S,S-trimethyl phosphorodithioate, is approximately 500 times more toxic than malathion. Furthermore, according to Umetsu et al. (1977), the concentrations of these impurities increase during storage, particularly in the three to six months following manufacture, and also when exposed to high temperatures (100 degrees F.).

Effects on Animals and Plants/Environmental Persistence and Potentiation

Animals. The U.S. Department of the Interior (1985) concluded that there is no clear evidence that malathion causes cancer in rats or mice. Research on malathion cited by Smith (1987) found that the chemical has slight to moderate acute oral toxicity to birds and mammals, but is toxic to bees, fish, and some aquatic organisms. Hudelson (1988) reported that the acute toxicity level for cutthroat trout is 280 micrograms (10^{-6} gram) per liter of water.

According to Extoxnet (1993a) and Ohio State University (1997), malathion is moderately toxic to birds, but highly toxic to aquatic invertebrates, some fish including cutthroat and brown trout, the aquatic stages of amphibians, and honey bees. Indeed, Pegg (1992) cited a study that showed significant mortality of adult honey bees with reduced pollination and honey production by the survivors following malathion exposure.

Research by American Cyanamid, summarized by Hudelson (1988), found that hens appeared to be unaffected by diets containing malathion concentrations of 250 ppm. At 1000 ppm, there was some evidence of adverse effects on food consumption, growth, and plasma cholinesterase activity, but results were inconclusive. The acute toxicity level for cattle was found to be 53 milligrams per kilogram of body weight.

Sinclair and Pressinger (1997) reviewed a number of studies on wildlife exposed to malathion. A Rutgers University study found that concentrations of malathion in water as low as five ppm caused heart defects in some fish. Concentrations as low as one ppm were found to cause head and tail deformities and abnormal swimming behavior in frog tadpoles. Lizards exposed to one milligram of malathion per kilogram of body weight sustained liver, kidney, and intestinal damage.

Neufeld (1990) reported mortality in Canada geese following ingestion of malathion-treated grass. Rosenbaum et al. (1988) and Caballero de Castro et al. (1991) found that malathion exposure caused either developmental delays or death in toads depending on length of exposure.

Some researchers, when studying effects of malathion on organisms, often use the term "toxicity" to mean the amount of pure chemical required to cause death in laboratory animals. This terminology is misleading because 1) technical grade, rather than pure, malathion is most often used in community spraying programs, and 2) numerous effects short of death are frequently noted. For example, the amount of malathion necessary to cause death in most mammals is over 500 milligrams per kilogram, but the above-noted studies indicate that animals can experience negative effects at much smaller dosages. Similarly, a TR-192 bioassay test of malathion (1979) found no evidence of carcinogenicity in rats, but did find that decreased body weight, increased mortality, gastritis, and gastric ulcers were malathion dose-related in male rats.

Plants. Pegg (1992) cites research on vetch, soybean, and wheat plants indicating that malathion has been found to inhibit photosynthesis, seedling growth, and root cell respiration, and to cause chromosome damage.

Soils. According to the U.S. Department of the Interior (1985), malathion is persistent in soil for one week. Hudelson (1988) referred to an American Cyanamide study that indicated 50-90% of the initial quantity of malathion was degraded in 24 hours. Sinclair and Pressinger (1997) cited a study showing that malathion was reduced by 75% in soil within 10 days, but that the highly toxic breakdown product malaoxon was still present. Pegg (1992) summarized research showing that malathion and its breakdown products inhibited soil microorganisms for 30 days.

Water. Because of malathion's toxicity to fish, use over or around water is not recommended. Degradation of the chemical in water is influenced by pH and temperature.

Potentiation. Interactions between pesticides often produce a potentiating effect. That is, the interaction can result in greater toxicity than would be anticipated from the individual pesticides. Potentiation can occur on farms, orchards, or ranches, for example, where a number of chemical agents might be used to control a variety of pests such as garden insects, mosquitoes, or fruit fungi. Walker and Johnston (1997) reported that partridges exposed to a fungicide exhibit greater susceptibility to malathion, because the fungicide increases the liver enzyme that converts malathion to malaoxon. According to Fred Lamming, there is some use of fungicide in Teton County.

Options

Tuttle (1995) of Bat Conservation International stated that mosquito control is too complex a problem to be solved by a single approach, whether it be pesticides or bat houses, and that many options should be considered.

Because chemical spraying only provides short-term relief to mosquito problems, Holscher (1996) and Lajeunesse (1997) recommended targeting control efforts at the larval stage with biorational controls such as B.t.i. Cost is an issue, however. According to Fred Lamming (pers. comm.), the cost of malathion spraying is about three dollars an acre. Because of the labor and time necessary to monitor larval development, however, larvicide treatments range from seven to ten dollars an acre.

The University of Wyoming Agricultural Extension Service (1985) recommended physical control, where possible, to reduce mosquito breeding habitat. The elimination of standing water will result in fewer places for mosquitoes to lay eggs. Drain or fill holes in yards and grade driveways to keep water from collecting in low spots. Large numbers of mosquitoes can be produced in very small amounts of standing water (Lajeunesse 1997). Keep yards free of containers that hold water such as cans, jars, buckets, wheelbarrows, bird baths, old tires, upright canoes. Clean roof gutters to keep water draining, and fix dripping outdoor faucets so puddles cannot form.

Snug-fitting screens on windows and weatherstripping around doors can prevent mosquitoes from entering homes. In New England, screen-in porches are more common than open decks, particularly on cottages near lakes and ponds where mosquitoes and black flies are abundant.

A range of chemical and natural commercial mosquito repellants are available. When using repellants, individuals are free to make choices based on their own personal needs and values.

In an effort to reduce their dependence on chemicals for mosquito control, city officials in Riverton, Wyoming have joined forces with the University of Wyoming to experiment with native mosquito-eating minnows called killifish (Casper Star-Tribune 1997). The minnows multiply quickly under optimal conditions and consume large numbers of mosquito larvae. In spring of 1998, minnows will be released into streams, ponds, and potholes around Riverton to prey on mosquito larvae.

Insectivores such as bats, swallows, and purple martins can play an important role in mosquito control and should be encouraged. According to Tuttle (1995) and Harris (1996), individuals of some bat species can consume 500 to 1000 mosquitoes in one hour, and large bat colonies can eat several tons of mosquitoes a year. Tuttle (1995), however, stated that there is no guarantee that bats can be attracted to an area, regardless of the availability of roosts. The successful use of manmade roosts is most likely to occur where bats are already present and using other roosting areas, such as old buildings, barns, or bridges. At least six species of bats inhabit the Jackson Hole area (Haraden 1995). One of these, the little brown bat, is abundant and feeds on mosquitoes.

Conclusions

Of the mosquito control practices used in Teton County, aerial spraying of malathion is by far the most controversial. I expect that each side will find information in this paper to promote its own opinion. Proponents of a more natural approach will likely focus on the health and environmental dangers of malathion, while spraying advocates will key in on data claiming that malathion is one of the least toxic insecticides available.

With no cases of encephalitis occurring in Wyoming last year and equine infectious anemia determined rare in the state, the threat of disease transmission hardly justifies an aggressive mosquito eradication program. There is no doubt, however, that mosquito infestations are an annoyance to residents and visitors eager to enjoy summer outdoor activities.

Scientific research, such as that presently being conducted by TCWPD, will provide us with valuable information about the status of mosquitoes in the county. In the meantime, county residents must decide what control methods should be used.

Aerial spraying of the adulticide malathion offers a temporary solution at best because mosquitoes from unsprayed areas readily migrate into treated lands. Because adult mosquitoes are mobile, adulticide treatments are less efficient than larvicides that attack the source of the problem. There are well-founded concerns about malathion's toxicity to people, wildlife, and the environment. Furthermore, mosquitoes will likely develop resistance to the chemical in the future.

Biorational larvicides presently appear to be environmentally safe and highly effective in preventing large numbers of larvae from maturing into adults. Their application is time-consuming and costly, however, due to necessary monitoring of larval development and precise timing of applications. Presently TCWPD provides larvicide briquets to landowners for use on their property. More extensive use of larvicides will require increased funding for field personnel and training on larvicide application for landowners.

Fred Lamming (pers. comm.) recommends a greater dependence on larvicides than adulticides in Teton County, with emphasis on an educational program in larvicide use for landowners. He would like to see more public interest in the program, and added that enthusiastic landowners, like Cal Mathieu, who have taken the time to learn larval monitoring techniques, have had great success with larvicide treatments. It can be difficult, however, to generate public interest in the program early enough in the season to be effective. People often don't think about mosquitoes until summer, when adults are biting, but larval monitoring and effective larviciding must begin in late winter and early spring.

Although the Weed and Pest District administers the mosquito abatement program, its funding is generously provided by the taxpayers of Teton County. Lamming is eager to generate more community involvement through informational public meetings and educational sessions.

We must accept the fact that we cannot eliminate all mosquitoes. Approximately 97% of Teton County is federal land, where no mosquito control occurs other than natural predation. Mosquitoes fly great distances, assuring that they will move into the remaining 3% of county land, even with aggressive control procedures. Furthermore, there will be more years like 1997 when wetter than average conditions produce bumber crops of mosquitoes.

It is likely that the mosquito abatement controversy will continue in Teton County. County officials and residents must examine the facts and make informed decisions for the common benefit of all living things. If this paper has given people a broader understanding of this highly-charged issue, it will have achieved its purpose.

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