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Mosquito Control Pesticides: Adverse Impacts to Freshwater Aquatic and Marine Organisms

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Abstract. Most toxicity information available for evaluating potential effects of mosquito control chemicals on non-target aquatic biota comes from acute lethality tests of 24- to 96-hr duration. These studies generally show that insecticides are more toxic to aquatic invertebrates than fishes. Crustaceans, in particular, are extremely sensitive to mosquito control insecticides, perhaps a result of their close phylogenetic relationships with insects. Effects of longer-term exposures on survival and growth or studies that quantify other sublethal effects are available only for selected, standard laboratory test species for some chemicals. Field studies conducted by our laboratory following operational insecticide applications have shown that exposures can be shorter duration and of lesser concentration than those used for worst-case scenarios in screening-level environmental risk assessments. However, long-term effects of repeated applications of the same chemical or cumulative effects of multiple-chemical treatments have not been adequately assessed in the field.

Approaches to Establishing Potential Hazards of Pesticides

Most of the toxicity information available to evaluate potential effects of mosquito control chemicals on non-target aquatic biota comes from acute lethality tests of 24- to 96-hr duration. Effects of longer-term exposures on the survival, growth and reproduction of aquatic biota are assessed less frequently using standardized chronic toxicity testing approaches (ASTM 1988 a,b,c) and shortened, chronic effect estimator tests (USEPA 1987, 1989). These toxicity data form the base of a tiered approach generally applied to environmental risk assessment (Dickson et al. 1979), which has been developed into a standardized approach for pesticide registration (Urban and Cook 1986). Contemporary environmental risk assessments and use restrictions for pesticides use laboratory data on the acute and chronic toxicity of a pesticide to establish exposure-response relationships that are then compared to expected or measured concentrations under actual use conditions.

Information on acute and chronic toxicity is limited to those species that can be readily tested under laboratory holding conditions. In order to ensure that regulatory controls and use restrictions will be protective of the numerous species which can not be cultured or tested in the laboratory, environmental risk assessments employ a series of worst-case exposure scenarios using the toxicity test results for the most sensitive species tested. Other factors, such as potential bioaccumulation by aquatic biota and chemical fate and persistence in aquatic habitats, also are considered in environmental risk assessment of mosquito control chemicals (Urban and Cook 1986).

Because laboratory tests are conducted under conditions that optimize the survival of test species except for exposure to test chemicals, there are questions as to the applicability of the exposure-response relationships for animals in the field that might be stressed by fluctuations in temperature, salinity, dissolved oxygen availability, food availability, etc. On the other hand, laboratory test conditions provide for constant exposure concentrations for the duration of the test (e.g., 24 hr, 96 hr, 14 days) and deny test animals protective behavioral responses such as avoidance of contaminated areas. Thus the degree of environmental protection offered by routine environmental risk assessment procedures can be questioned as being insufficient or over-protective when the process is scrutinized in detail. Attempts to verify the applicability of environmental risk assessment processes by conducting exposure-response studies under field conditions have provided some insight into these questions, but considerable work still needs to be done.

This paper will discuss common mosquito control chemicals and present selected examples of acute and chronic toxicity data from standard laboratory tests using a variety of freshwater and marine species. The comparative sensitivities of these non-target species is discussed. Also, these data will be examined as to the degree to which the exposure-response data represent conditions that reflect actual-use applications of insecticides for mosquito control or resemble the actual ecological reality of environmental contamination. Examples of exposure-response relationships from field studies of application of mosquito control chemicals in Florida will provide some perspective on the utility of various approaches used for pesticide risk assessments. This paper will limit considerations to malathion, fenthion, dibrom, or temephos because they are generally used by mosquito control operations in Florida for wide-scale applications that could potentially affect permanent water bodies.

Acute Toxicity to Aquatic Biota

Johnson and Finley (1980) and Mayer and Ellersiek (1986) present acute toxicity test results for a variety of freshwater invertebrates and fishes tested with a large number of chemicals, including malathion, fenthion, dibrom, and temephos. Toxicity of these mosquito control chemicals to various marine species is reported in Mayer (1987), Borthwick et al. (1985), and Parrish et al. (1977). Mulla et al. (1979) reviewed laboratory and field toxicity of mosquito control insecticides. Selected data for the subject mosquito control chemicals are presented in Table 1. These selected and limited examples generally show that malathion, fenthion, dibrom and temephos are more toxic to aquatic invertebrates than fishes. Crustaceans, in particular, are extremely sensitive to organophosphorus chemicals, perhaps a result of their close phylogenetic relationships with insects. Because there can be up to seven orders-of-magnitude difference in LC50 concentrations among the most sensitive species and other fishes and invertebrates tested (Mayer and Ellersieck 1986), pesticide use restrictions and controls designed to protect the most sensitive species should provide protection for most other aquatic, non-target biota.

Chronic Toxicity to Aquatic Biota

Effects of longer-term exposures on survival and growth or studies that quantify other sublethal effects are available only for selected, standard laboratory test species for some chemicals. Malathion has been studied extensively due to its widespread use. Threshold effects for chronic toxicity of malathion have been reported at 200 to 580 ug/l for fathead minnows (Mount and Stephan 1967), 4 to 7 ug/l for bluegills (Eaton 1970), and 4 to 9 ug/l for sheepshead minnows (Parrish et al. 1977). These chronic effects data were obtained from tests where adult fish were tested for up to 140 days and tests with their progeny that lasted 28 days in laboratory systems. McKenney (1986) reported that mysid growth was reduced after 4 days exposure to fenthion maintained at concentrations $\geq$0.17 ug/l and that exposure concentrations $\geq$0.08 ug/l maintained for 14 days significantly inhibited mysid growth. Reproduction also was affected by 14 days of continuous exposure to fenthion $\geq$0.08 ug/l. No other published information concerning chronic exposure toxicity tests with invertebrates or fishes and malathion, fenthion, dibrom, or temephos were revealed in a search of the literature.

Environmental Persistence

All of the mosquito control chemicals of interest degrade readily in aquatic environments. Malathion degrades rapidly, with a half-life of 4 to 8 days, when released into aquatic habitats with pH and temperature ranges of 6.5 to 8.5, and 15 to 30 C, respectively (Bourquin 1977, Wolfe et al. 1977). The aquatic half-life of fenthion is 4 to 7 days, with enhanced degradation in habitats with plant components and sediment- associated bacteria (Cripe et al. 1989, O'Neill et al. 1989). Dibrom breaks down within hours by chemical hydrolysis once it enters aquatic environments, leading to rapid decreases in exposure concentrations for aquatic organisms (Chen 1984). Temephos concentrations also diminished in the course of 2 to 3 days in marine habitats (Lores et al. 1987, Pierce et al. 1989, 1990). Because these insecticides degrade or are mixed and diluted to very low or non-detectable concentrations within days of entering aquatic habitats, it seems unlikely that exposures beyond those used for acute toxicity assessments are needed to accurately characterize potential risks to aquatic biota under most mosquito control use conditions. However, research needs for assessing sub-lethal and long-term effects of repeated, pulse exposures are discussed in a subsequent section.

Field Studies of Pesticide Effects

Several mosquito control districts and state laboratories in Florida have participated in field studies of operational applications of malathion, fenthion, and temephos to determine effects on non-target, aquatic species.

Malathion was quantified in environmental samples at concentrations $\leq$10% of the values predicted by worst-case exposure scenarios for truck or aerial ultra-low-volume (ULV) application (Tucker et al. 1986, 1987). These concentrations decreased to non-detectable levels within 48 hours and no acute toxicity among fish or invertebrates held in cages at the field site was observed. Ground ULV and thermal fog applications of malathion in a saltmarsh had no acute toxicity to fish and invertebrates (Tagatz et al. 1974). Concentrations of malathion measured in water samples from the treated area ranged from 0.49 to 5.2 ug/l.

Fenthion has been studied in the field by our laboratory (Clark et al. 1987) and by staff at the Harbor Branch Research Laboratory (Tucker et al. 1986, 1987, Wang et al. 1987). These studies have shown that exposures of estuarine biota to fenthion are of shorter duration and of lesser concentrations than those used for worst-case scenarios in screening-level environmental risk assessments. Measured environmental concentrations following ground ULV or aerial thermal fog applications of fenthion were at least an order of magnitude less than those predicted by risk assessment assumptions of 100% deposition in an acre-foot of water (Clark et al. 1987). Tidal mixing and exchange diminished concentrations of fenthion to non-detectable levels in open, estuarine environments. In poorly flushed areas with minimal mixing, the chemical persisted for up to 4 days at concentrations that were not acutely toxic to test species. Estuarine biota such as mysids, penaeid shrimp, spotted seatrout and sheepshead minnows maintained in cages at several test sites were not more sensitive to fenthion than expectations based on laboratory toxicity data.

Dibrom has not been studied extensively due to its lack of persistence in the environment and difficulty in quantitative analyses. A study conducted over freshwater habitats on a military base in Georgia reported environmental concentrations ≤10.5 ug/l 30 minutes after application, with non-detectable residues at 24 h post-application, the only other sample time (Livingston et al. 1974). No threat to aquatic resources was observed in this study. Test applications of dibrom at operational mosquito control rates near estuarine environments by aerial, truck mounted, or lawn equipment resulted in no significant mortality among test populations of shrimp, crabs, and fish (Bearden 1967). Environmental chemistry was not included in the study.

Mosquito larvicide applications of temephos have been studied by Pierce et al. (1989, 1990) in mangrove habitats of south Florida. Toxicity from temephos exposure was not observed among five species of non-target crustaceans and fish studied in the field. Measured environmental concentrations were close to predicted concentrations immediately after larvicide applications directly over water, but tidal dilution and mixing as well as biodegradation diminished concentrations in open habitats within hours after application. Similar environmental concentrations and persistence in mangrove habitats have been reported by Lores et al. (1987). Applications of temephos to freshwater ponds at labeled mosquito larvicide rates had no adverse impact on bluegill survival with minimal impact on aquatic invertebrates other than mosquito larvae (Sanders et al. 1981).

Additional Data Needs

What was not tested in any of these field experiments was whether the sublethal concentrations of insecticides persisted for sufficient duration to result in adverse effects on populations of sensitive crustaceans. Extended exposures to non-lethal concentrations of mosquito control insecticides could result in diminished growth or impairment of reproduction among non-target species such as mysids, however long-term characterizations of exposure concentrations have not been completed. The long-term effect of repeated exposures to short-term pulses of pesticide throughout a mosquito season also have not been thoroughly assessed. Sublethal effects on non-target larvae are being addressed by the Mote Marine Laboratory in Sarasota, FL, through field studies of larvicide application of temephos (R. Pierce, Mote Marine Lab, personal communication). The cumulative effects of multiple-chemical exposures of aquatic biota in an urban setting that includes pesticide application activities such as insect control by homeowners, lawn services, golf courses in addition to mosquito control have not been adequately assessed in the field.

This paper is not intended to provide an extensive or comprehensive review of effects of mosquito control chemicals on all non-target aquatic species. Rather, the reader should review the environmental issues and risk assessment approaches discussed in the various papers presented at this symposium, and use this paper as a source of issues for considering the extent to which laboratory toxicity data used in the environmental hazard assessment match the exposures and responses observed in the field. It is unlikely that field studies will cover all exposure-response scenarios in all habitats, thus we must rely on conceptual approaches to various exposure scenarios and laboratory toxicity test data to provide a comprehensive basis for decision making and environmental risk assessment. The accuracy and applicability of those approaches and data should be evaluated within the context of their intended use.

Table 1. Acute toxicity of malathion, fenthion, dibrom and temephos to selected freshwater and marine organisms. All LC50 values reported as ug/l from 96-h tests unless otherwise noted. Daphnia tests are EC50 results based on immobilization of test animals.

Insecticide Species	96-h LC50	Ref
Malathion (Cythion)		
Freshwater species		
Water flea *(Daphnia pulex)*	1.8 (48-h)	1
Amphipod *(Gammarus fasciatus)*	0.76	1
Glass shrimp *(Palaemonetes kadiakensis)*	90	1

Insecticide Species	96-h LC50		Ref
Fathead minnow *(Pimephales promelas)*	8,650		1
Channel catfish *(Ictalurus punctatus)*	8,970		1
Bluegill *(Lepomis macrochirus)*	103		1
Largemouth bass *(Micropterus salmoides)*	285		1
Saltwater species			
Mysid *(Mysidopsis bahia)*	5.0		2
Pink shrimp *(Penaeus duorarum)*	20		2
Grass shrimp *(Palaemonetes pugio)*	30		2
Silverside *(Menidia beryllina)*			
Sheepshead minnow *(Cyprinodon variegatus)*	51		3
Spot *(Leisotomus xanthurus)*			
Fenthion (Baytex)			
Freshwater species			
Water flea *(Daphnia pulex)*	0.8	(48-h)	1
Amphipod *(Gammarus lacustris)*	8.4		1
Glass shrimp *(Palaemonetes kadiakensis)*	10		1
Fathead minnow *(Pimephales promelas)*	2,440		1
Channel catfish *(Ictalurus punctatus)*	1,600		1
Bluegill *(Lepomis macrochirus)*	1,380		1
Largemouth bass *(Micropterus salmoides)*	1,540		1
Saltwater species			
Mysid *(Mysidopsis bahia)*	0.15		4
Pink shrimp *(Penaeus duorarum)*	0.11		4
Grass shrimp *(Palaemonetes pugio)*	4.7	(48-h)	4
Silverside *(Menidia beryllina)*	2,150	(48-h)	4
Sheepshead minnow *(Cyprinodon variegatus)*	1,890	(48-h)	4
Spot *(Leisotomus xanthurus)*	1,200	(48-h)	4
Dibrom (Naled)			
Freshwater species			
Water flea *(Daphnia pulex)*	0.4	(48-h)	1
Amphipod *(Gammarus fasciatus)*	18		1
Glass shrimp *(Palaemonetes kadiakensis)*	92		1
Fathead minnow *(Pimephales promelas)*	3,300		1
Channel catfish *(Ictalurus punctatus)*	710		1
Bluegill *(Lepomis macrochirus)*	2,200		1
Largemouth bass *(Micropterus salmoides)*	1,900		1
Saltwater species			
Mysid *(Mysidopsis bahia)*	13		5
Pink shrimp *(Penaeus duorarum)*	6.6		5
Grass shrimp *(Palaemonetes pugio)*	16		5
Silverside *(Menidia beryllina)*	2,800	(48-h)	5
Sheepshead minnow *(Cyprinodon variegatus)*	1,900	(48-h)	5
Spot *(Leisotomus xanthurus)*	240	(48-h)	5
Temephos (Abate)			
Freshwater species			
Water flea *(Daphnia pulex)*			
Amphipod *(Gammarus lacustris)*	80		1
Glass shrimp *(Palaemonetes kadiakensis)*			
Fathead minnow *(Pimephales promelas)*	34,000		1
Channel catfish *(Ictalurus punctatus)*	>10,000		1

Insecticide Species	96-h	LC50	Ref
Bluegill *(Lepomis macrochirus)*	1,140		1
Largemouth bass *(Micropterus salmoides)*	1,440		1
Saltwater species			
Mysid *(Mysidopsis bahia)*			
Pink shrimp *(Penaeus duorarum)*	10		5
Grass shrimp *(Palaemonetes pugio)*			
Silverside *(Menidia beryllina)*	3,900	(48-h)	5
Sheepshead minnow *(Cyprinodon variegatus)*			
Spot *(Leisotomus xanthurus)*	>1,000	(48-h)	5

Key to References
1 - Johnson and Finley (1980); 2 - Clark et al. (in prep); 3 - Parrish et al. (1977); 4 - Borthwick et al. (1984) 5 - Mayer (1987).

Most toxicity information available for evaluating potential effects of mosquito control chemicals on non-target aquatic biota comes from acute lethality tests of 24- to 96-hr duration. These studies generally show that insecticides are more toxic to aquatic invertebrates than fishes. Crustaceans, in particular, are extremely sensitive to mosquito control insecticides, perhaps a result of their close phylogenetic relationships with insects. Effects of longer-term exposures on survival and growth or studies that quantify other sublethal effects are available only for selected, standard laboratory test species for some chemicals. Field studies conducted by our laboratory following operational insecticide applications have shown that exposures can be of shorter duration and of lesser concentration than those used for worst-case scenarios in screening-level environmental risk assessments. However, long-term effects of repeated applications of the same chemical or cumulative effects of multiple-chemical treatments have not been adequately assessed.

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16. ABSTRACT

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