Bull. Environm. Contam. Toxicol. 25, 846-853 (1980)

Toxicity of Five Forest Insecticides to Cutthroat Trout and Two Species of Aquatic Invertebrates

D. F. Woodward[1] and W. L. Mauck[2]

[1] *Columbia National Fisheries Research Laboratory, Field Research Laboratory, United States Department of Interior, Fish & Wildlife Service, P.O. Box 1089, Jackson, WY 83001;* [2] *Columbia National Fisheries Research Laboratory, United States Department of Interior, Fish & Wildlife Service, Route 1, Columbia, MO 65201*

The Northern Rocky Mountain region has had scattered infestation of the western spruce budworm Christoneura occidentalis since the early 1900's (U.S. DEPARTMENT OF AGRICULTURE (USDA) 1976b). On the basis of aerial surveys in 1975, TUNNOCK et al. (1976), estimated that budworm defoliation occurred on 2,278,804 acres of six National Forests in Montana. Since the use of DDT was banned in 1972, there has been a need to develop alternative insecticides with the efficacy of DDT but without its environmental risk. These insecticides must be effective in controlling the budworm, but should not persist in the environment or be toxic to other organisms. The organophosphate and carbamate insecticides are relatively nonpersistent and generally present only a moderate hazard to fish when applied according to label recommendations. The USDA Forest Service has been investigating the effectiveness of these two classes of insecticides against the budworm, and the Columbia National Fisheries Research Laboratory of the U.S. Fish and Wildlife Service has been cooperating with the Forest Service conducted pilot control projects in eastern Montana in 1975 and 1976 to determine the efficacy and environmental impact of acephate, carbaryl, and trichlorfon in controlling the western budworm (USDA 1976 b). In 1975, a similar type project was carried out in Maine with aminocarb, fenitrothion, and trichlorfon (USDA 1976 a).

Acephate, fenitrothion, and trichlorfon (organophosphate insecticides) and aminocarb and carbaryl (carbamate insecticides) were selected for toxicity tests against cutthroat trout (Salmo clarki), a stonefly (Pteronarcella badia), and a freshwater amphipod (Gammarus pseudolimnaeus) edemic in streams of the northern Rocky Mountains. Populations of cutthroat trout inhabit lakes and streams in the Rocky Mountains which include some of the most pristine habitat and fisheries in North America. Pteronarcella and Gammarus provide forage for cutthroat trout and feed on decaying vegetation in riffle areas in streams and rivers. Stonefly naiads and amphipods were selected as test organisms because of their importance as trout food and their wide distribution in mountain stream communities. We determined the effect of various water types representing different

0007-4861/80/0025-0846 $01.80

biogeographical areas in the Intermountain West on the toxicity of these five forest insecticides.

MATERIALS AND METHODS

Technical grade and field formulations of insecticides used in the toxicity tests were obtained from the following sources: aminocarb and trichlorfon--Chemagro Agricultural Divison of Mobay Chemical Corporation; acephate--Ortho Division of Chevron Chemical Company; carbaryl--Union Carbide Corporation; and fenitrothion--Sumitomo Chemical Company, Japan. Stock solutions with commercial grade acetone were prepared immediately before each test; all concentrations mentioned apply to active ingredient.

To test the influence of pH and hardness on insecticde toxicity, we prepared media with different quality characteristics, according to MARKING and DAWSON (1972), by adding reagent grade salts, mineral acids, or bases to deionized water. The pH of test solutions was measured daily and adjusted, wherever necessary, to maintain the appropriate pH. Test temperatures were controlled by water baths.

Cutthroat trout were obtained from the Jackson Wyoming National Fish Hatchery and maintained according to the procedures reported by BRAUHN and SCHOETTGER (1975). Fish were held in 9.5° C water and acclimated to test conditions for 24 h before exposure.

Stonefly naiads were collected from the Snake River below Teton National Park, Wyoming, and held in a laboratory stream before they were used in tests. Amphipods were collected from small springs and held in laboratory chambers before the tests. Stoneflies and amphipods were held in 12 C water and acclimated to test conditions 24 h before exposure.

Acute toxicity tests were performed according to methods recommended by the COMMITTEE ON METHODS FOR TOXICITY TESTS WITH AQUATIC ORGANIMSMS (1975). Mortality data from all tests were analyzed statistically (LITCHFIELD AND WILCOXON 1949) to determine the 96-h LC50's (concentrations producing 50% mortality in 96-h) and 95% confidence intervals.

RESULTS

Fish. Toxicities of the insecticides tested ranged from 88 µg/l to more than 100,000 µg/l for cutthroat trout (Table 1). On the basis of tests with the technical materials, the order of toxicity from most to least toxic was trichlorfon, fenitrothion,

TABLE I

The acute toxicity of technical and field formulations of five forest insecticides to cutthroat trout in 12 C softwater at pH 7.5. Toxicity is based on active ingredients.

Chemical, formulation and percent active ingredient	96-h LC50 at 95% Confidence Interval µg/ℓ
Acephate	
Technical, 94%	>100,000
Formulation, 75%	>100,000
Aminocarb	
Technical, 98%	28,000 24,000-32,600
Formulation, 17%	88 73-106
Carbaryl	
Technical, 99%	3,950 3,040-5,130
Formulation, 49%	6,700 5,230-8,600
Fenitrothion	
Technical, 95%	2,880 2,340-3,550
Formulation, 87%	2,880 2,400-3,260
Trichlorfon	
Technical	1,680 1,430-1,980
Formulation	3,250 2,740-3,860

carbaryl, aminocarb, and acephate. The field formulation of carbaryl and trichlorfon were less toxic than the technical material. However, one of the most significant findings from these tests was the discovery that the field formulation of aminocarb (17% active ingredient) was over 300 times more toxic than the technical grade material. There were no differences in toxicity between technical and formulated acephate or fenitrothion.

The toxicity of trichlorfon increased about 3.4 fold when the water temperature was increased from 7 to 12 °C at pH 7.5 (Table 2), and increased by a factor of 13 when pH was increased from 6.5 to 8.5, and increased by a factor of 2.7 when water hardness was increased from 6.5 to 8.5 the toxicity of aminocarb was increased by a factor of 20 and carbaryl by a factor of 5. Toxicities of acephate and fenitrothion were not significantly affected by changes in temperature (7-12°C), pH (6.5-8.5), or water hardness (40-320 mg/l).

Invertebrates. The LC50's of the five insecticides to amphipods and stoneflies ranged from 4.3 to more than 25,000 g/l (Table 3). In soft water at 12 ° C and pH 7.5, carbaryl, fenitrothion, and trichlorfon were the more toxic to both species; aminocarb was intermediate in toxicity; and acephate was by far the least toxic. Stoneflies were more sensitive than amphipods to acephate, aminocarb, and trichlorfon, but amphipods were the more sensitive to carbaryl. There was no apparent difference between sensitivity of the two species to fenitrothion. The toxicity of trichlorfon to amphipods increased twofold when pH was increased from 7.5 to 8.5, and toxicity to stoneflies was increased nearly 20-fold when pH was increased from 6.5 to 8.5. Decreasing the pH from 8.5 to 6.5 increased the toxicity of acephate and carbaryl to stoneflies by factors of 3.3 and 2.6, respectively. However, amphipods were nearly 2 times more sensitive to carbaryl at pH's of 7.5 and 8.5 than at 6.5. Fenitrothion was 2 times more toxic to amphipods at pH 6.5 than at pH 7.5.

DISCUSSION

The stonefly naiads and the amphipods were considerably more sensitive than cutthroat trout to all of the chemicals except aminocarb 17% (Tables 1, 2, and 3). This finding could be expected because all five insecticides are cholinesterase inhibitors and have a different toxicity to insects than to vertebrates (NATIONAL ACADEMY OF SCIENCES 1971). The nerves of insects are more accessible than fish, and the differences in metabolism between insects and fish promote activation of organophosphates and carbamates in invertebrates and inactivation in fish (LOOMIS 1974).

TABLE II

The influence of water temperature, pH, and hardness
on the acute toxicity of five forest insecticides to cutthroat trout.

Test conditions			96 h LC50 and 95% confidence interval (μg/ℓ)				
Temp (C)	pH	Water Hardness 1/	Acephate (94%)	Aminocarb (98%)	Carbaryl (99%)	Fenitrothion (95%)	Trichlorfon (99%)
7	7.5	soft	>100,000	27,000 21,500-34,000	6,000 4,630-7,770	2,700 2,160-3,380	5,750 4,910-6,740
12	6.5	soft	> 50,000	26,500 21,500-32,600	5,000 4,100-6,100	2,770 2,360-3,250	4,750 3,840-5,870
12	7.5	soft	>100,000	28,000 24,000-32,600	3,950 3,040-5,130	2,880 2,340-3,550	1,680 1,430-1,980
12	8.5	soft	> 60,000	1,300 1,090-1,560	970 770-1,220	2,570 2,060-3,200	375 310-454
12	7.8	very hard	> 50,000	24,500 19,400-31,000	3,950 3,370-4,630	2,780 2,380-3,250	620 490-780

1/ Soft, 40 μg/ℓ as CaCO ; very hard, 320 μg/ℓ.

TABLE III

The 96-h LC50's (μg/ℓ) of five insecticides to (A) amphipods (*Gammarus pseudolimnaeus*) and (S) stoneflies (*Pteronarcella badia*) at selected pH's in softwater 12 C under static conditions.

	Insecticide and percentage active ingredient									
	Acephate (94%)		Aminocarb (98%)		Carbaryl (99%)		Fenitrothion (95%)		Trichlorfon (99%)	
pH	A	S	A	S	A	S	A	S	A	S
6.5	>25,000	6,400	-	28	13	11	4.3	5.1	-	100
		5,200-7,800		18-43	8.9-19	9.7-13	2.1-8.6	4.3-6.1		73-137
7.5	>25,000	9,500	2,200	19	7.0	13	8.8	7.2	108	9.8
		7,300-12,300	1,500-3,300	15-26	4.1-11.9	12-16	6.7-12.4	5.6-9.2	70-166	8.3-12
8.5	>25,000	21,200	1,000	26	7.2	29	5.6	5.5	52	5.3
		15,600-28,800	-	20-33	5.6-9.3	21-41	3.5-9.1	4.3-7.0	40-68	3.9-7.1

Of importance to resource managers is the significant increase in toxicity of some insecticides when formulated, or when tested in water of different pH, hardness, or temperature. Formulated aminocarb was over 300 times more toxic to cutthroat trout than was technical aminocarb. Similar results have been observed for rainbow trout (Salmo gairdneri) and bluegills (Lepomis macrochirus) exposed to technical and formulated aminocarb (A.M. JULIN, personal communication). Apparently the 17% formulated aminocarb is composed of material having a greater toxicity than the active aminocarb, or possibly there was a synergistic effect between the active and inactive ingredients in the formulated aminocarb. We also found that trichlorfon was not only one of the more toxic forest insecticides tested, but that its toxicity increased at high temperature (12°C) and pH (8.5), and in very hard water (320 mg/l as $CaCO_3$). Under environmental conditions where all three of these water quality variables favor an increase in trichlorfon toxicity to aquatic organisms, this chemical would be a poor choice as a forest insecticide. Other insecticides showing a five-fold or greater change in toxicity with different water quality were technical aminocarb and carbaryl in pH tests with fish.

Significance of our toxicity tests can best be interpreted if the results are related to water residues resulting from field applications of the insecticides studied. HAUGEN (1976) and G.N. HAUGEN (personal communication) reported that the application of 1 lb/acre (1.12 kg/ha) acephate and carbaryl in western Montana resulted in maximum steam residues of 961 and 260 μg/l, respectively. Streams monitored in Maine after application of 1 lb/acre (1.12 kg/ha) carbaryl, and 2 oz/acre (140 μg/ha) fenitrothion resulted in the following water residues: trichlorfon 7.0 μg/l; carbaryl 13 μg/l; and fenitrothion 6.6 μg/l (USDA 1976 a). Fenitrothion concentrations up to 6.4 μg/l were measured in a Canadian stream after the chemical was applied to surrounding forest land (EIDT 1975). The range of residues in water reported after spraying varied greatly, but maximum concentrations detected were below 1,000 g/l and seldom exceeded 15 μg/l (EIDT and SUNDARMA 1975).

Assuming that field application of the insecticides studied could result in concentrations up to 1,000 μg/l in natural waters, aminocarb (17%) would be acutely toxic to cutthroat trout. Also, at the higher pH's of 7.5 and 8.5, which are characterisic of western Montana streams (HAUGEN 1976), trichlorfon would be acutely toxic to cutthroat trout at 375 μg/l and carbaryl at 970 μg/l. With the exception of formulated aminocarb, all five insecticides appear to be safe to cutthroat trout at pH's of 7.5 and below; however, acephate offers by far the greatest margin of safety to aquatic organisms.

Because of the sensitivity of amphipods and stoneflies to aminocarb, carbaryl, fenitrothion, and trichlorfon, the greatest impact from spraying would be on aquatic invertebrates. Field evaluations support this statement. Increased drift of mayflies and stoneflies was recorded for two Montana streams after aerial application of carbaryl and trichlorfon (G.N. HAUGEN, personal communication). In similar studies in Canada, EIDT (1975) reported that water residues of 6.4 µg/l fenitrothion in Canada were associated with a large kill of aquatic insects. Although water residues do not normally exceed 15 µg/l, stream residues at this concentration would result in acute mortality of amphipods exposed to carbaryl and fenitrothion and of stonefly naiads exposed to carbaryl, fenitrothion, or trichlorfon; however, aminocarb concentrations greater than 19 µg/l would be acutely toxic to stoneflies. Although one kill may not have a major effect on total producion (EIDT 1975), it may change community structure and reduce food availability for the fish population.

Acephate was the most acceptabe forest insecticide tested from the standpoint of impact on non-target aquatic organisms. This finding agrees with the results of SCHOETTGER and MAUCK (1978) with brook trout (Salvelinus fontinalis). Acephate was non-toxic to cutthroat trout and the lowest concentrations that were toxic to aquatic invertebrates were much higher than the concentrations that could be expected in post-spray water residues. One field study supported our laboratory findings and emphasized the importance of using an insecticide with low toxicity to non-target aquatic organisms: HAUGEN (1976) reported that stream residues up to 961 µg/l acephate did not affect invertebrate drift in a Montana stream. Residues at this magnitude with aminocarb, carbaryl, fenitrothion, or trichlorfon would have resulted in a substantial kill of amphipods, stoneflies, and probably other aquatic invertebrates.

Although acephate should be considered the safest forest insecticide to fish and aquatic invertebrates, it may pose a serious hazard to songbirds. Acephate applied at 2 lb/acre significantly inhibited cholinesterase in songbirds for several weeks (C. HENNY personal communication).

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