

Effects of Permethrin on Aquatic Organisms in a Freshwater Stream in South-Central Alaska

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J. Econ. Entomol. 85(3): 860-864 (1992)

ABSTRACT Permethrin (0.5%) was applied to individual Lutz spruce, *Picea x lutzii* Little, to protect them from attack by spruce beetles, *Dendroctonus rufipennis* (Kirby). Residue levels were monitored in a freshwater stream above, adjacent to, and below the treatment site at intervals before, during, and after treatment. Maximum residue levels in the stream within the treatment site ranged from 0.05 ± 0.01 ppb 5 h after treatment to 0.14 ± 0.03 ppb 8-11 h after treatment, with a decrease to 0.02 ± 0.01 ppb 14 h after treatment. Levels of permethrin in standing pools near the stream within the treatment site were 0.01 ± 0.01 ppb. Numbers of drifting aquatic invertebrates increased 2-fold during treatment and 4-fold 3 h after treatment and declined to before spray numbers within 9 h. Terrestrial insects did not appear to respond to treatments because none was found in stream drift samples. Trout fry (Dolly Varden), aquatic insect larvae, and periphyton (attached algae) within and below the treatment site during and after treatment did not show signs of mortality compared with an upstream untreated control site.

KEY WORDS Insecta, aquatic effects, aquatic organisms, insecticide residue

A FIELD STUDY was done in south-central Alaska to determine the efficacy of permethrin, chlorpyrifos, and fenitrothion to protect trees from attack by spruce beetles, *Dendroctonus rufipennis* (Kirby). Permethrin was more effective than the other insecticides in protecting trees and had less effect on natural populations of parasites and predators of the spruce beetle (Werner et al. 1983, 1984). Data on the persistence of residues in bark, soil, and pools of standing water from areas within and adjacent to trees treated with permethrin was collected previously (Werner et al. 1984). Additional information was needed on the aquatic effects of permethrin before the status of registration of permethrin for use against spruce beetles could be decided.

The effects of aerial application of insecticides to protect forest ecosystems has been monitored for many years (McEwen & Stephenson 1979), and the results of studies of pesticide residues in aquatic systems have been reported (Eidt 1975, 1978; Coady 1978; Kingsbury & Kreutzweiser 1979, 1980a, b; Kreutzweiser 1982; Morin et al. 1986; Muirhead-Thomson 1978; Poirier & Surgeoner 1987, 1988; Woodward & Mauck 1980). The long-term effects of pesticides on forest ecosystems were reported for fenitrothion and the pyrethroids by the National Research Council of Canada (1977, 1986).

South-central Alaska contains high-value spruce stands that are often susceptible to attack by spruce beetles. The region also has some of the best anadromous fish habitat and sport fishing streams in North America. Effects of insecticides on survival and densities of fish fry and other aquatic organisms in cold-water streams of Alaska are unknown; therefore, our research was conducted to determine the effect of permethrin on aquatic organisms.

Materials and Methods

A field test of insecticide efficacy was conducted along a freshwater stream on the Chugach National Forest in south-central Alaska. Application methods and effects on spruce beetle populations were reported by Werner et al. (1984). Permethrin (Pounce 0.5% EC [emulsifiable concentrate], FMC Corporation, Princeton, N.J.) was applied with a hydraulic sprayer at a pressure of 31.65 g/cm^2 to the bark surface of individual trees to a height of 12 m until the bark was thoroughly wet. Treatment plots were located within 5 m of the stream. The effects of permethrin on water chemistry, population levels of aquatic and terrestrial organisms, and residue levels were monitored at three locations in the stream: an untreated control area 800 m above the treatment area, within the treatment area (an area fronting the stream for 100 m), and 500 m below the treatment area. The stream was "2 m wide and 0.3 m deep at all sampling locations.

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† Deceased.

Tobie 1. Toxo ond number of specimens used ot eoh monitoring site

| Taxon | Above treatment (control) | Within treatment | Below treatment |
|--|---------------------------|------------------|-----------------|
| Plecoptera | | | |
| Perlodidae and Chloroperlidae | 10 | 10 | 10 |
| Ephemeroptera | | | |
| Hepta/eniidae | 10 | 10 | 10 |
| Baetidae | 10 | 10 | 10 |
| Ephemerellidae | 10 | 10 | 10 |
| Dolly Varden trout (<i>Salvelinus</i> spp.) | | | |
| IIIa/ma | | | |
| 2 cm Ion/ | 4 | 5 | 3 |
| 5 cm Ion/ | 3 | 3 | 3 |

Density and composition of aquatic invertebrates were examined before and after treatment for toxic effects on the benthic population. Chambers (biomonitors) within streams were used to determine mortality rates of acclimated native organisms within 24 h after treatment. Drift was monitored to determine if aquatic invertebrates exhibited a catastrophic drift as a result of permethrin drifting into the stream, and if terrestrial insects exhibited a drop down response to insecticide spraying. Periphyton (attached algae) was collected and analyzed for permethrin residues. Dissolved chemicals from stream water were measured before and after treatment to determine if gross toxicity to the periphyton community resulted in death and decay of standing algal crops, a process that could release nutrients in higher concentrations than background levels.

Biomonitors used for enclosing organisms consisted of clear plexiglass tubes (7.62 cm in diameter and 20.32 cm long) with 273-mesh Nitex screen (Carolina Biological Supply Company, Burlington, N.C.) on the ends. These were anchored on the bottom of the stream at riffle sites. Stoneflies (Plecoptera) and mayflies (Ephemeroptera) were used in the monitors because they were indigenous to the stream. Two biomonitors with 10 specimens of each taxon (Table 1) were placed at the untreated control, within, and below the treatment site and allowed to acclimate for 1 d before treatment.

Dolly Varden trout fry, *Salvelinus malma* (Walbaum), were collected at night from drift nets and placed in the biomonitors with several macroinvertebrates (Plecoptera and Ephemeroptera) as a source of food. Two size classes (2 cm and 5 cm in length) of ~ fry per biomonitor were monitored at each site.

Specimens within the biomonitors were examined hourly for activity during the 24-h period immediately after treatment. Aquatic invertebrates were examined by placing watertight caps over the biomonitor ends, removing the biomonitor from the stream, and tipping it so the organisms sank and could be observed through the

clear plexiglass. Aquatic invertebrates that exhibited active swimming behavior were recorded as live specimens. Specimens that did not swim were further examined for movement with a hand lens; if inactive, they were teased with forceps to induce movement. Organisms were considered dead and were removed if no movement was observed after probing.

Drift of aquatic and terrestrial invertebrates was sampled before, during, and after treatment on an hourly basis with drift nets anchored to the bottom of the streams. Two drift nets were used per sampling site because the stream was only 2 m wide. Net openings measured 1,340 cm² and nets were 1 m long; netting was composed of 273-mesh Nitex.

Benthic invertebrates were collected below the treatment site before and after the treatment with five replicate Surber (American Public Health Association 1975) samples (0.093 m²) from the same riffle where drift was measured. We hypothesized that if permethrin had a detrimental effect on the benthic population, organism densities would be greatly reduced after the treatment.

Rocks containing periphyton were collected from the bottom of the stream at all three sites before, during, and after treatment. Periphyton was removed by scraping rocks with a wire brush and samples were frozen in polyethylene containers until analysis. Periphyton biomass was measured as ash-free dry mass based on scrapings from three replicate circular areas (5-cm diameter) from submerged rocks (American Public Health Association 1975).

Water samples for dissolved nutrients (NO₂-N, NO₃-N, NH₃-N, Kjeldahl-N, ortho-P, and total-P) and cations (Ca, Mg, Mn, Na, K, Si) were collected in prewashed polyethylene bottles, stored, and analyzed in the laboratory using standard methodologies (American Public Health Association 1975).

Water samples for analysis of permethrin residues were collected hourly during and after treatment and placed in prerinsed polyethylene jugs. The samples were frozen and analyzed at the University of Georgia, Athens, Ga. Permethrin residues in the water samples were extracted into 100 ml hexane. Analysis was performed by gas chromatography. An electron capture detector was used to analyze for permethrin using a 180-cm glass column packed with 1.5% OV-17/1.95% QF-1 on Chromosorb W (100/120 mesh); oven temperature was 235°C. No important interfering materials were present in the extracts.

Water and algal samples were fortified with known quantities of permethrin and compared with standards to determine recovery efficiency (Johnson & Finley 1980). Samples were fortified at 0.001 ppm for water and 0.05 ppm for algal suspensions and processed as described above.

Recovery efficiency ($\bar{x} \pm SD$) for three replicates each was $100 \pm 7\%$ for water and $70 \pm 3\%$ for algae.

Data were subjected to an ANOVA program from the CoStat (1986) statistical package; means were separated by Bonferroni's multiple comparison test (Dunn & Clark 1987).

Results and Discussion

Permethrin was applied from 0700 to 0800 hours on 23 May. Residues measured in water samples within the site during this time period were below detection levels; however, residue levels reached 0.05 ± 0.01 ppb 5 h after treatment (1300 hours), 0.09 ± 0.02 ppb 6 h after treatment (1400 hours), 0.14 ± 0.03 ppb 8 h after treatment (1600 hours), 0.14 ± 0.04 ppb 11 h after treatment (1900 hours), and 0.02 ± 0.01 ppb 14 h after treatment (2200 hours). Residues measured from the sites above and below the treatment contained <0.01 ppb of permethrin throughout the sampling period. Permethrin residues from pools from melting snow within the treated site were less than 0.01 ± 0.01 ppb after treatment.

Biomass of periphyton from each monitoring site increased slightly after the treatment period. Growths of periphyton were dominated by *Hydrurus foetidus* (Vill.) Trev., a filamentous chrysophyten species common in cold, well-oxygenated, fast-flowing streams throughout the region. Diatoms common in the region (*Diatoma vulgare* Bory, *Hannaea arcus* (Ehr.) Patr., *Cocconeis placentula* Ehr., *Meridion circulare* (Grev.) Ag., and species of *Fragilaria*, *Navicula*, and *Nitzschia*) were also found within the periphyton.

We hypothesized that if permethrin caused gross algal mortality, cell death and decomposition would cause an increase in nitrogen and phosphorus compounds in stream water. We observed no apparent increase in cation or anion concentrations after treatment. Permethrin residues from periphyton collected from the three monitoring sites were all <0.02 ppm, indicating that permethrin residues in the sites within and below the treatment were not present in sufficient concentrations for long enough times to be adsorbed onto or absorbed into the periphyton.

Drifting invertebrates were collected every 4 h the day before treatment (May 22) and at hourly intervals the day of treatment (May 23) starting at 0600 hours. Comparison of the 4-h drift samples before, during, and after treatment are shown in Table 2. Drift of aquatic invertebrates after treatment increased significantly ($P < 0.05$), but terrestrial invertebrate (hymenopteran and lepidopteran adults) levels remained unchanged. Terrestrial invertebrates comprised $<14\%$ of the total number of invertebrates collected in drift nets (Table 2). Numbers of drifting invertebrates increased 2-fold during treatment and 4-fold 3 h

Table 2. Comparison of number of macroinvertebrates ($\bar{x} \pm SD$) in 4-h intervals from drift samples at the downstream site before, during, and after treatment with permethrin

| Category | 23 May | | | | | | | | | | | |
|-----------------------|-----------|------------------------|-----------|-----------|-----------|-----------|-----------|------------------------|-----------|-----------|-----------|-----------|
| | 0200-0600 | 0600-1000 ^a | 1000-1400 | 1400-1800 | 1800-2200 | 2200-2400 | 0200-0600 | 0600-1000 ^a | 1000-1400 | 1400-1800 | 1800-2200 | 2200-2400 |
| Terrestrial organisms | 9 ± 1 | 12 ± 3c | 2c | 23 ± 6b | 229 ± 44b | 18 ± 5a | 1 ± 1c | 18 ± 5a | 4a | 6 ± 1b | 10 ± 3b | 10 ± 3b |
| Aquatic organisms | 5 ± 1 | 98 ± 17d | 12d | 229 ± 44b | 252 ± 50b | 361 ± 76a | 170 ± 36c | 361 ± 76a | 84a | 55 ± 14d | 209 ± 32b | 209 ± 32b |
| Total organisms | 14 ± 2 | 110 ± 21c | 13d | 252 ± 50b | 481 ± 94b | 379 ± 81a | 171 ± 33c | 379 ± 81a | 102a | 61 ± 16d | 219 ± 40b | 219 ± 40b |
| Percent terrestrial | 64 ± 7 | 11 ± 3a | 4a | 9 ± 2b | 9 ± 2b | 5 ± 1b | 1 ± 1c | 5 ± 1b | 2b | 10 ± 3a | 5 ± 2b | 5 ± 2b |

Means within rows followed by the same letter are not significantly different ($P < 0.05$; Bonferroni multiple comparison test [Dunn & Clark 1987]).

^a Time of treatment was 0700-0800 hours on 23 May.

Table 3. Summary of macroinvertebrates collected from drift nets at the downstream site at hourly intervals before, during, and after treatment on the day of treatment (May 23)

| Organism | Time interval, hours | | | | | | | | | | | |
|---------------|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| | 0600-0700 | 0700-0800 | 0800-0900 | 0900-1000 | 1000-1100 | 1100-1200 | 1200-1300 | 1300-1400 | 1400-1500 | 1500-1600 | 1600-1700 | 1700-1800 |
| Diptera | 4c | | | | | | | 6c | | 4c | | 4c |
| Ephemeroptera | 2c | | | | | | 11b | | 8b | 6b | 8b | 5c |
| Hymenoptera | 0c | | | | | | 0c | | 1c | 1c | 1c | 1c |
| Lepidoptera | 0c | | | | | | 0c | | 0c | 1c | 0c | 1c |
| Plecoptera | 1c | | | | | | 9b | | 6b | 6b | 7b | 9b |
| Trichoptera | 2b | | | | | | 2b | | 3b | 2b | 2b | 1b |
| Total | 10e | | | | | | 11c | | 12c | 10d | 12d | 11e |

Mean \pm SD from two replications. Means within rows followed by the same letter are not significantly different ($P < 0.05$, Bonferroni multiple comparison test [Dunn & Clark 1987]).

^a Time of treatment.

Table 4. Nunilier ($\bar{x} \pm SO$) of benthic organisms collected with a Surber sampler 2 d before and 5 d after treatment at the downstream site

| Organism | No./m ² | |
|---------------|--------------------|-----------------|
| | Before treatment | After treatment |
| Chironomidae | 375 \pm 95a | 2200 \pm 450a |
| Ephemeroptera | 50 \pm 21b | 56 \pm 17b |
| Oligochaeta | 45 \pm 15b | 50 \pm 16b |
| Plecoptera | 30 \pm 12b | 34 \pm 18b |
| Trichoptera | 14 \pm 2c | 20 \pm 6c |

$n = 5$. Means followed by the same letter are not significantly different ($P < 0.05$; Bonferroni multiple comparison test [Dunn & Clark 1987]).

after treatment; within 9 h, numbers declined to levels observed before spray application (Table 3). Dipteran (Chironomidae) larvae, ephemeropteran (Ephemeroptera) larvae, and trichopteran (Limnephilidae) larvae accounted for the increase in total drift.

Aquatic invertebrates and fish fry caged in biomonitors did not appear to exhibit increased mortality because of the permethrin treatment. Biomonitor data indicated that only one plecopteran died within the treatment site within 24 h after treatment and no mortality of caged organisms was observed at sites above or below the treatment. No Dolly Varden fry died in either of the two size classes up to 24 h after treatment. Permethrin residues in the stream were lower than those reported as toxic to aquatic organisms in the short term (Johnson & Finley 1980, Mayer & Ellersieck 1986).

A summary of laboratory toxicities is provided by the U.S. Fish and Wildlife Service (Mayer & Ellersieck 1986) and by Johnson & Finley (1980). Although taxa from those studies were not used in this study, some organisms can be chosen from the literature as representative of taxa from comparable groups and habitats. The LC₅₀ of permethrin was 4.4 ppm for rainbow trout over a 24-h exposure. Continuous-flow laboratory bioassays (Poirier & Surgeoner 1987) performed on *Simulium venustum* (Diptera: Simuliidae) and *Pycnopsyche* sp. (Trichoptera) resulted in a LC₅₀ of 4.5 and 3.2 ppb at 48 h.

Five Surber samples were taken in a single rime area at the downstream site before treatment (21 May) and after treatment (28 May) to compare taxonomic composition and density of organisms (Table 4). The number ($\bar{x} \pm SD$) of organisms from five Surber samples was 514 \pm 113 per m² on 21 May and 2,360 \pm 630 per m² on 28 May. This significant ($P < 0.05$) increase in densities was attributable to an 83% increase in chironomid larvae, whereas oligochaete, ephemeropteran, plecopteran, and trichopteran densities were unchanged.

We concluded from the experiments described here that permethrin caused mortality to freshwater invertebrates in south-central Alaska when

sprayed on individual spruce trees with a hydraulic sprayer. Drift of aquatic invertebrates increased significantly after treatment of spray plots. However, trout fry, periphyton, and benthic invertebrates were not affected. Permethrin residues were only found in water samples from the treatment area. No detectable residues were found 500 m downstream from the treatment area.

Acknowledgment

We thank R. Averill, E. Holsten, F. Hastings, D. Lyon, R. Wolfe, K. Zogas, K. Post, C. Kingery, J. Quigley, T. Torgerson, and M. Abare (USDA Forest Service), for their assistance in application of insecticides and subsequent collection of water and algal samples and biomonitor data. We also thank the late U. E. Brady (University of Georgia) for the insecticide residue analysis of the water and algal samples. Personnel of the Seward Ranger District, Chugach National Forest, provided logistical support. M. Oswood and A. Jones (University of Alaska) conducted macroinvertebrate sample processing and identifications. We thank F. Hastings (North Carolina State University), J. G. Irons (USDA Forest Service), and M. Oswood (University of Alaska) for comments about this manuscript.

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Received for publication 15 April 1991; accepted 20 December 1991.