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Impact of Chemigation on Selected Non-Target Aquatic Organisms in Cranberry Bogs of British Columbia

M. T. Wan, R. G. Watts, D. J. Moul

Environment Canada, Conservation and Protection, Environmental Protection, Pacific & Yukon Region, 224 West Esplanade, North Vancouver, British Columbia, Canada V7M 3H7

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Chemigation is an alternate method of applying insecticides to cranberry bogs for the control of the blackheaded fireworm, Rhopobota naevana Hubner. This technique involves the injection of a pre-calculated concentration of an insecticide into the sprinkler irrigation system. The irrigation system delivers and distributes the chemical to the field via a network of underground PVC pipes. Rotating sprinkler heads are permanently installed at pre-selected locations for uniform spray coverage in the cranberry fields. The chemical injection is usually programmed to last the equivalent of about 10 min of field irrigation, with the sprinkler system set to remain in operation for the next 0.5 hr.

Chemigation is normally conducted in late evening or at night, when the effect of cooling air inversion ensures minimum insecticide evaporation, aerial drift, and impact on non-target terrestrial organisms such as foraging bees and birds in the cranberry fields. The objective of this study was to determine the short term in situ chemigation impact of azinphos-methyl (AZI) and parathion (PAR) on selected non-target aquatic organisms in the receiving aquatic environment adjacent to cranberry bogs.

MATERIALS AND METHODS

The common names and rates of application of test materials are summarized in Table 1. Guthion^{R} was supplied by Chemagro, Etobicoke, Ontario; and Parathion 960 was obtained from United Agri Products, London, Ontario.

The impact assessment was undertaken by using rainbow trout (Oncorhynchus mykiss), stickleback fish (Gasterosteus aculeatus), and daphnids (Daphnia magna) as test organisms.

A preliminary laboratory static test was conducted to examine the suitability of using salmonids as test fish. Ten rainbow trout were placed in a test vessel containing a sample of 20 L aerated peat water obtained from a waterway near the cranberry fields. A

Correspondence to: M. T. Wan

Table 1. Test materials

Common name	Rate of application	Concentration of active ingredient
Azinphos-methyl (Guthion[R])	1.1 kg a.i./ha	0,0-dimethyl-S-[4-oxo-1,2,3-benzo-triazin-3(4H)-yl)methyl]phosphorodithioate (240 g active ingredient/L)
Parathion	0.96 kg a.i./ha	0,0-diethyl 0-p-nitrophenylphosphorothioate (960 g active ingredient/L)

100% fish mortality was observed within 24 hr, indicating that rainbow trout could not survive the low pH (av. pH = 4.5) condition of the peat water, and that this species was not a suitable test fish. A similar test was conducted in the laboratory using daphnids. The test showed that this crustacean could survive 48 h in peat water. Accordingly, it was selected as an indicator organism for aquatic invertebrates. Stickleback was selected as the test fish species, since it was one of the few resident fish that could be trapped in large numbers during the test period (May to June) from the bog aquatic environment outside the chemigated fields. Both daphnids and juvenile stickleback were placed in cages deployed in situ at representative locations (Fig. 1: A, B, C_1 - C_4) in the cranberry bogs 24 hr prior to chemigation.

Daphnids were placed in 0.25-L tubular plastic invertebrate cages (8 cm id x 8 cm). An elastic band was used to secure a piece of stretched nylon stocking which covered each end of the tubular plastic cage to prevent the escape of test organisms. The cage was then attached by elastic bands to a metal fork, which was inserted into the ditch bank substrate to secure the device from being swept away by any water current. Four replicate cages, each containing 15 daphnids, were deployed at each test site.

A 30-L aluminum framed, fish field cage (20 cm x 40 cm x 45 cm) was used to hold the stickleback. At each test site two replicate cages were deployed, each containing 15 fish (age = 2 $\pm$ 0.2 mo; length = 4.2 $\pm$ 0.4 cm; wt = 0.8 $\pm$ 0.1 g).

Two cranberry bogs were studied: (1) Sidaway Road, Richmond (lat. 49°10′N, long. 123°6′W), British Columbia; and (2) Harris Road, Pitt Meadows (lat. 49°15′N, long. 122°41′W), British Columbia, (Figure 1).

The Richmond cranberry bog represented an "open" bog system. This system allows water containing pesticide residues to discharge freely to the receiving environment, e.g., a roadside ditch. It was chemigated with AZI on May 5, May 23, and June 25, 1992, at the rate of 1.1 kg a.i./ha. The 24 hr impact observations on

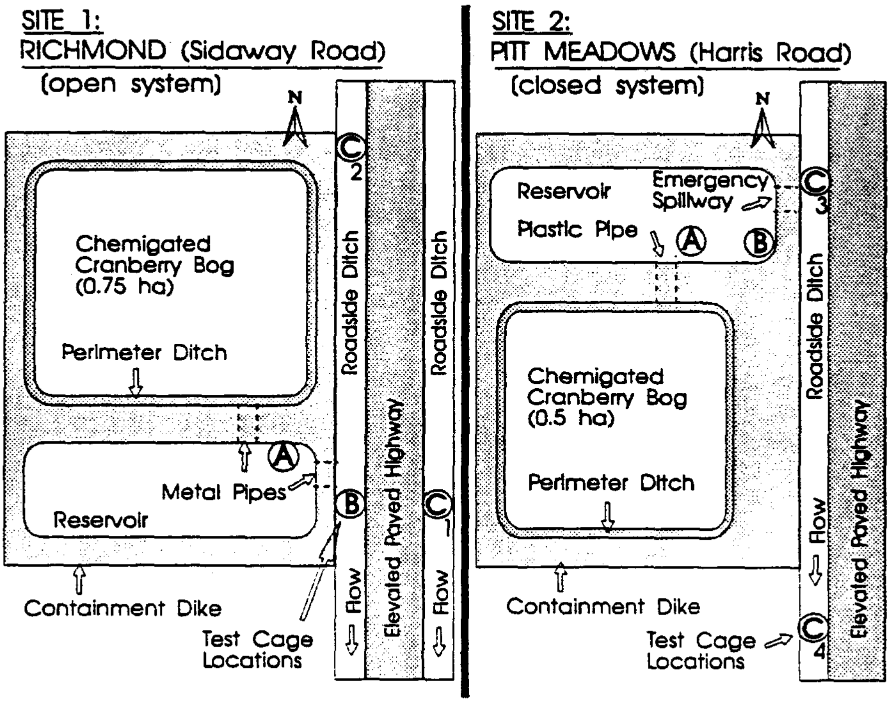

Figure 1. Schematic Diagram of the Two Study Sites (not drawn to scale)

daphnids were conducted on May 5-6, 1992, while the 96 hr observations on stickleback were carried out from June 25, to June 29, 1992. This diked bog contained a 0.75 ha bed of cranberries, with a drainage ditch along the perimeter of the field, and another ditch alongside the roadway adjacent to a 2-m wide containment dike (Figure 1). Water from the bog flowed to the SE corner of the field and drained to a reservoir through a 20 cm diameter metal pipe which passed through the dike.

Although an attempt was made to retain the ditch water in the bog by blocking the 20 cm metal pipe, a small leak from the perimeter ditch to the reservoir developed and continued throughout the study period (May 5 - June 30, 1992). Excess water in the reservoir could be released to the roadside ditch through a gate-regulated 60 cm diameter corrugated metal pipe. In this study, the flow of water from the reservoir to the ditch outside was not regulated in order to simulate a worse case scenario of chemical release.

Two test locations (A & B) and two controls stations (C_1 & C_2) were selected (Figure 1): A - inside the reservoir ; B - in the roadside ditch; two control stations = C_1 (for daphnids) across the paved highway, and C_2 (for stickleback fish) about 50 m upstream of the cranberry bog at Richmond in the roadside ditch.

The Pitt Meadows cranberry bog is a "closed" system in which water containing pesticide residues is prevented from discharging to the to the receiving environment. This bog was chemigated with PAR on May 4, June 2, and June 30, 1992 at the rate of 0.96 kg a.i./ha each time. The 24 hr daphnid impact study was carried out on May 4-5, 1992, while the 96 hr observations on fish were conducted on June 30 - July 5, 1992. This study bog is located about 40 km NE of Richmond. It contains plots arranged in a series of ten 0.5 ha bogs, each of which drains to a common reservoir and is separated by a 2m-wide containment dike (Figure 1).

A 4 m wide earthen dike separated the reservoir from the roadside drainage ditch outside the cranberry farm. However, this earthened dike contained a spillway ditch (about 0.6 m above normal water level of reservoir) to allow excess water (resulting from unusally heavy storm events) to drain out of the reservoir.

Two test cage locations (A & B) and two control stations (C_3 & C_4) were also selected for the impact tests (Figure 1): A - in the reservoir near the treated cranberry field; B - in the reservoir near the emergency spillway ditch; (C_3 & C_4) - controls in the ditch outside the 4 m earthen dike.

Peat water samples from both bog study areas were collected for determinations of AZI, PAR, and organochlorine (OC) pesticide residues, and for water quality. The screening of water samples for extractable metals, nutrients, and chlorinated pesticides was conducted at Conservation & Protection Laboratory, West Vancouver, British Columbia, using in-house methods developed by Environment Canada (1989). Azinphos-methyl and parathion residue analyses in water were performed by the Research Station Laboratory of Agriculture Canada, Vancouver, B.C., Canada, using the analytical method outlined by Szeto et al. (1990). The % recoveries for AZI and PAR in water (detection limit for both compounds = 0.05 ug/L) were 86.9 $\pm$ 3.4 and 83.8 $\pm$ 3.9 (mean $\pm$ S.E., n = 4) respectively. The test to determine the significance of mean differences was carried out by using the student's t test (Alder and Roessler, 1968).

RESULTS AND DISCUSSION

Residues of the following compounds were not found in the water samples (n = 3) obtained from Sidaway Road and Harris Road ditches: total DDT, BHC, PCB, PCP, picloram, and simazine.

The 24 hr test results of daphnids exposed in situ to AZI and PAR residues resulting from the May 1992 chemigation are presented in Tables 2 and 3.

In Richmond, there was a 100% daphnid mortality in the reservoir at test cage location (A) which received runoff from the cranberry bog. Seventy-seven percent of the test organisms died when placed in ditch at location B, which was connected to, but situated 4 m outside, the reservoir (Figure 1). However, at the control location C_1, a 40% mortality of the crustacean was also observed.

Table 2. Mortality of daphnids and water quality conditions at Richmond, 24-h post chemigation (Mean ± S.E.; n = 3)

Test cage locations	Reservoir[1] (A)	Ditch[1] adjacent reservoir (B)	Control[1] (C_1)
Water conditions of test sites (May 4, 1992)			
Conductivity (umhos/cm)	60 ± 1	70 ± 4	125 ± 12
D.O. (mg/L)	7.2 ± 0.4	8 ± 1	4.2 ± 0.5
Hardness(total; mg/L $CaCO_3$)	19 ± 1	29 ± 2	60 ± 3
metals[a] (total; mg/L)	1.2 ± 0.1	2 ± 0.4	4.5 ± 0.7
pH (rel. U.)	4.5 ± 0.1	5.6 ± 0.1	5.6 ± 0.1
Temperature (°C)	11	11	11
AZI residue[b] (Mean, ug/L)	114	1.3	ND[c]
Mortality (mean %; n = 4[d])	100	77	40

1 - see Figure 1; a - Al, Ca, Fe, K, Mg, Mn, Na, P, Si, Sr, Zn; b - Wan et al. (1993); c - ND = not detected (detection limit = 0.05 ug/L); d - 4 cages, each containing 15 daphnids

Table 3. Mortality of daphnids and water conditions at Pitt Meadows, 24-h post chemigation (Mean ± S.E.; n = 3)

Test cage locations	Reservoir[1] (A)	Reservoir[1] (B)	Control[1] (C_3)
Water conditions of test sites (May 6, 1992)			
Conductivity (umhos/cm)	25 ± 5	25 ± 4	45 ± 3
D.O. (mg/L)	8.7 ± 0.2	9 ± 0.1	3.6 ± 0.6
Hardness(total; mg/L $CaCO_3$)	50 ± 2	8 ± 2	8.5 ± 1.5
Metals[a] (total; mg/L)	0.9 ± 0.2	0.7 ± 0.1	0.9 ± 1
pH (rel. U.)	4.3 ± 0.2	4.2 ± 0.3	5.6 ± 0.3
Temperature (°C)	18 ± 0.3	17 ± 0.4	16 ± 0.2
PAR residue[b] (mean, ug/L)	2.1	ND[c]	ND
Mortality (mean %; n = 4[d])	100	100	80

1 - see Fig. 1; a, b, c, and d - see Table 2

The water quality in terms of conductivity, D.O., hardness and metal content at the test locations did vary significantly ($p < 0.05$) between the control (C1) and treated areas (A & B) throughout the duration of the test, (Table 2). No detectable level of AZI was found at the control location, whereas grab water samples from the reservoir and the ditch outside the dike contained 114 ug/L and 1.3 ug/L AZI (detection limit = 0.05 ug/L), respectively, during the first 24 hr (Wan et al. 1993).

At Pitt Meadows, a 100% daphnid mortality was also found at both test locations, A and B, in the reservoirs (Figure 1). However, an 80% daphnid mortality was observed in the control location C_3.

The water quality of this test location in terms of conductivity, D.O., pH and temperature did differ significantly ($p < 0.05$) from values measured at locations, A and B, in the reservoir (Table 3). The concentration of PAR in water at B was not detected (detection limit = 0.05 ug/L), while 2.1 ug/L of this insecticide was detected in A (Wan et al. 1993).

The daphnid study was invalidated by the high mortality of the crustraceans in the controls at Pitt Meadows (C_3) and at Richmond (C_1). It would be difficult to attribute crustacean lethality to the effect of AZI and PAR residues. A number of other factors could have caused daphnid mortality, viz., stress on the test organisms; harsh environmental conditions, e.g., low pH and low dissolved oxygen; presence of high metal ions; or a combination of one or more of these factors (Tables 2 and 3). Based on these considerations, it was concluded that _Daphnia magna_ were not suitable test organisms for the in situ evaluation of pesticide impacts in the aquatic environment of peat bogs.

The test results of stickleback exposed for 96 hr in situ to AZI and PAR residues resulting from the June 1992 chemigation are presented in Tables 4 and 5.

In Richmond, a 100% fish mortality was observed in cages placed in the reservoir at location A and in those placed in the ditch at B, outside the reservoir (Figure 1 and Table 4). At the control location C_2, there was no fish mortality observed (Figure 1). The fish mortality in the ditch and the reservoir appeared to result from the presence of AZI residues in water. The AZI concentrations averaged 3.1 ug/L (range, 1.4 - 4.9 ug/L) and 3.6 ug/L (range, 2.6 - 4.6 ug/L) in the ditch and the reservoir, respectively (Table 4). There were no detectable AZI residues in the control test site. Fish mortality was likely caused by the pesticide residues, as the differences in water quality in terms of conductivity, D.O., metal content, pH and temperature of all three test cage locations did not differ significantly ($p < 0.05$) during the test period.

At Pitt Meadows, a 7% and 3% fish mortality was observed at two cage locations, A and B, respectively, in the reservoir (Figure 1 and Table 5). A fish mortality of up to 10% is not considered to be significant. The lethality was probably attributed to natural causes other than the low concentration of PAR (0.8 ug/L) detected in the treated bog plots. There was no fish mortality observed in the cages (C_4) in the control ditch, even though the water quality in terms of conductivity, D.O., hardness, metal content and pH at the three test locations did vary significantly ($p < 0.05$) at the time of testing. Supersaturated dissolved oxygen readings were observed at test locations A & B.

Unlike the tests with the daphnids, the in situ assessments using stickleback appeared to provide a more clear cut measurement of pesticide residue impact. Mortality of the test fish was likely caused by the presence of pesticide residues in the aquatic medium. Being native to the bog environment, the fish could

Table 4. Mortality of stickleback fish and water conditions at Richmond, 96-h post chemigation (Mean ± S.E.; n = 3)

Test cage locations	Reservoir[1] (A)	Ditch[1] adjacent reservoir (B)	Control[1] (C_2)
Water conditions (June 25 - 29, 1992)			
Conductivity (umhos/cm)	60 ± 2	107 ± 25	115 ± 30
D.O. (mg/L)	3.9 ± 0.7	4.1 ± 1	3.7 ± 0.5
Hardness(total; mg/L $CaCO_3$)	17 ± 1	20 ± 1	29 ± 1
Metals[a] (total; mg/L)	1.5 ± 0.1	1.6 ± 0.1	2.9 ± 0.4
pH (rel. U.)	4.9 ± 0.1	4.8 ± 0.1	5 ± 0.3
Temperature (°C)	21 ± 0.7	17.5 ± 2	18 ± 2
AZI residue[b] (mean ug/L; range)	3.6 (2.6-4.6)	3.1 (1.4-4.9)	ND[c]
Mortality (mean %; n = 2[d])	100	100	0

1 - see Figure 1; a - Al, Ca, Fe, K, Mg, Mn, Na, P, Si, Sr, Zn; b - Wan et al. (1993); c - ND = not detected (detection limit = 0.05 ug/L); d - 2 cages, each containing 15 fish

Table 5. Mortality of stickleback fish and water conditions at Pitt Meadows, 96-h post chemigation (Mean ± S.E.; n = 3)

Test cage locations	Reservoir[1] ditch (A)	Reservoir[1] (B)	Control[1] (C_4)
Water conditions (June 30 - July 4, 1992)			
Conductivity (umhos/cm)	50 ± 0.5	50 ± 1	137 ± 11
D.O. (mg/L)	11.4 ± 0.7	10.3 ± 0.2	3.2 ± 0.2
Hardness(total; mg/L $CaCO_3$)	14 ± 1	19 ± 2	36 ± 5
Metals[a] (total; mg/L)	1.5 ± 0.1	1.6 ± 0.1	6.2 ± 0.9
pH (rel. U.)	4 ± 0.1	4 ± 0.1	4.5 ± 0.1
Temperature (°C)	18 ± 0.5	17 ± 0.3	18 ± 0.5
PAR residue[b] (mean ug/L; range)	0.8 (0.8-0.9)	0.9	ND[c]
Mortality (mean %; n = 2[d])	7	3	0

1 - see Fig. 1; a, b, c, d - see Table 4.

survive the harsh water quality conditions of low pH and fluctuating dissolved oxygen and stress resulting from transportation, e.g., from Pitt Meadows to the Richmond (45 Km) test site. Pesticide residues were the only factor that could account for the fish mortality at the time of testing.

In summary, this study indicates that resident stickleback fish were suitable test organisms for in situ pesticide impact evaluation in a bog aquatic environment. The results suggest that AZI residue runoff from chemigated cranberry bogs was toxic to non-target resident fish when released into the aquatic environment outside the bogs. This observation further suggests that runoff from cranberry bogs treated with pesticides, especially AZI, should be contained within the bogs or in a reservoir protected by impervious dikes.

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REFERENCES

Alder HL, Roessler EB (1968) Introduction to probability and statistics. WH Freeman and Company, San Francisco

Environment Canada (1989) Metals and water; organochlorine pesticides screening. In: Conservation and Protection Laboratory Manual, Vancouver, British Columbia, Pacific & Yukon Region, p 1.1-1.8, 7.1-7.14

Szeto SY, Van MT, Price P (1990) Distribution and persistence of diazinon in cranberry bog. J Agri Food Chem 38:281-285