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Effects of Aerially Applied Mexacarbate on Western Spruce Budworm Larvae and their Parasites in Montana

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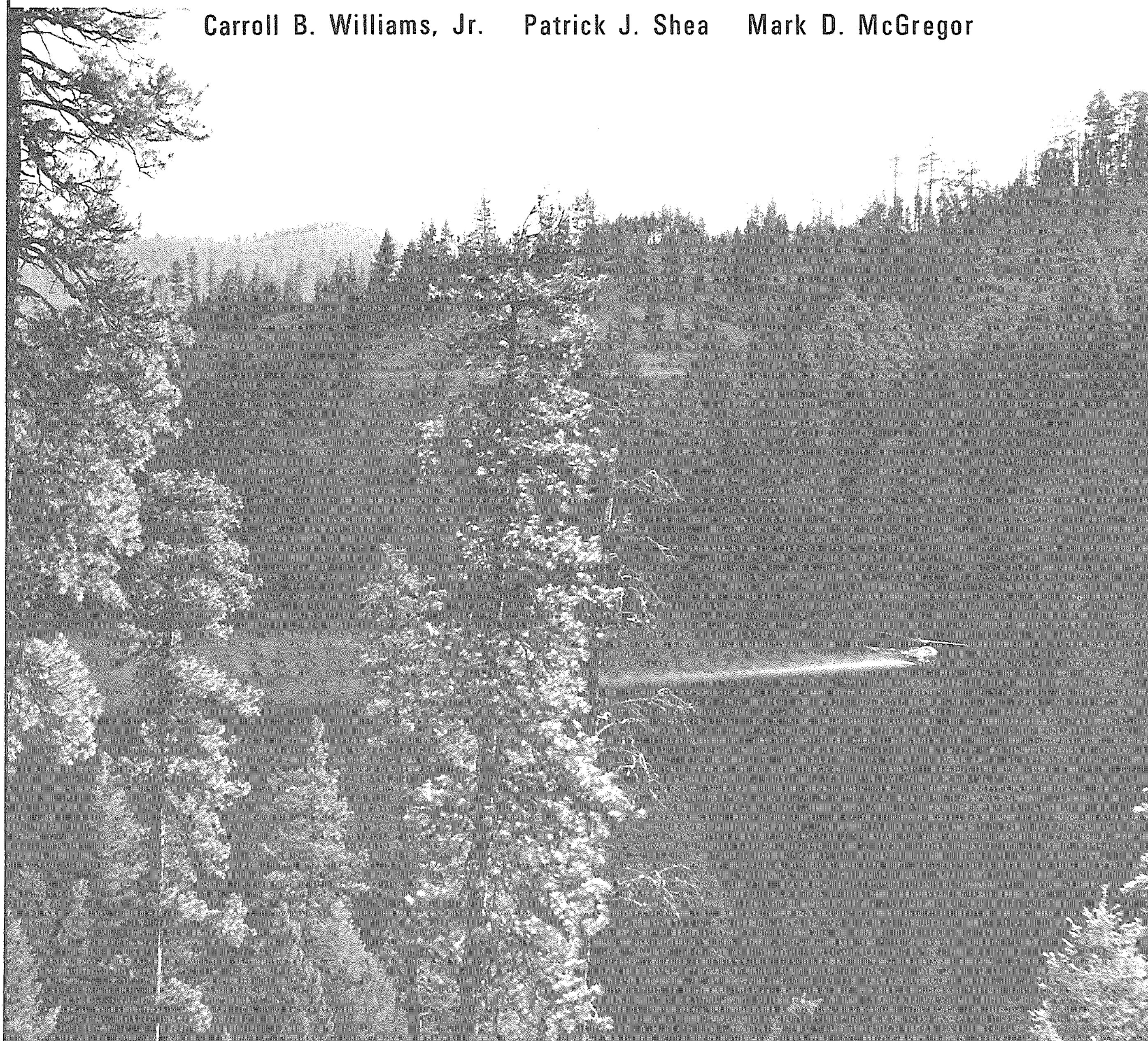

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CONTENTS

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IN BRIEF...

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Retrieval Terms: Insecticides; mexacarbate; naled; *Choristoneura occidentalis; Apanteles fumiferanae; Glypta fumiferanae; Phaeogenes hariolus; Mesochorus;* tachinids.

In 1965, 1966, and 1968, mexacarbate was aerially applied against western spruce budworm larvae (*Choristoneura occidentalis* Freeman) in budworm-infested forests of the Bitterroot National Forest in Montana. These field tests were designed to help assess mexacarbate, a nonpersistent insecticide, as a possible replacement for DDT. The tests would also provide opportunities for a study of spray distribution and spray droplet sizes as they relate to budworm mortality, and of the effects of mexacarbate on primary parasites of western spruce budworm larvae and other nontarget organisms, including several species of small mammals, birds, grouse, and fish, and fish habitat. The 1968 tests also included use of a nitrogen-pressurized spray system and evaluation of the process of atmospheric transport and diffusion which uses natural air movements to disseminate spray droplets throughout target areas. In 1969, the U.S. Environmental Protection Agency registered mexacarbate for use in suppressing the western spruce budworm.

The 1965 and 1966 mexacarbate applications were made in several drainages to the Bitterroot River. Treatment at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 l/0.404 ha) killed about 90 percent of the budworm larvae. Parasitized budworm larvae survived the treatments better than non-parasitized larvae. The overwintering parasites, *Apanteles fumiferanae* Viereck and *Glypta fumiferanae* Viereck, accounted for most of the subsequent increase in parasitism. The late larval, pupal parasites, primarily *Phaeogenes hariolus* (Cresson), *Mesochorus* sp., and tachinids also increased.

The 1968 tests were made on budworm-infested forests in two areas within the Blackfoot River drainage, east of Missoula, Montana. Mexacarbate, applied at the rate of 1 oz a.i./pt/acre (28.35 g a.i./473.16 ml/0.404 ha), suppressed 71 percent of the budworm populations in one area and 53 percent in the other.

In the 1965 and 1966 tests, parasitism increased in surviving budworm larvae of the treated generations, but tended to return to pretreatment levels the next year. In the 1968 tests, parasitism increased significantly in the areas of lowest budworm mortality and remained significantly higher than the 1968 prespray level for up to 2 years after treatment.

The 1965 and 1966 tests were considered successful in that the treatments killed about 90 percent of the budworm, but the 1968 tests were considered a failure in that less than 90 percent were killed. Higher parasite survival in the 1968 tests, however, provided unexpected information on several common parasites of the western spruce budworm.

The results suggest the possibility that non-persistent insecticides can be used to reduce directly epidemic budworm populations and to increase the ratio of parasites to budworm, thereby increasing parasite efficacy in control of budworm populations for several years after treatment.

Since 1969, mexacarbate has been officially registered by the U.S. Environmental Protection Agency (EPA) for use in suppression of the western spruce budworm (*Choristoneura occidentalis* Freeman), a major defoliator in Western United States. Leading to this registration were field tests which showed mexacarbate as an effective replacement for DDT in the suppression of budworm populations.

In 1965, a field test of naled and mexacarbate (Zectran)[1] against western spruce budworm larvae in several drainages of the Bitterroot National Forest in Montana, indicated that mexacarbate was a highly promising replacement for DDT. Naled was not as effective as mexacarbate in that budworm mortality was less. When applied at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 l/ 0.404 ha), mexacarbate suppressed the budworm population by about 92 percent (Williams and Walton 1968). Data indicated that mexacarbate was more toxic to western spruce budworm larvae than to larvae of associated defoliators (Williams and Walton 1968). Data also indicated that the mexacarbate treatment did not seriously affect the major parasites of western spruce budworm larvae during and immediately after spraying (Williams and others 1969).

On the basis of results of the 1965 field test, a pilot test of mexacarbate was made in early spring, 1966, on two additional budworm infested forests in the Bitterroot National Forest. Major objectives of this test were:

a. To test further mexacarbate at the dosage rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 l/ 0.404 ha) for suppressing western spruce budworm larval populations.

b. To provide opportunites for research scientists to try newer methods to more thoroughly investigate spray distribution, spray droplet sizes, and their relations to mortality in populations of budworm larvae.

c. To continue monitoring the effects of mexacarbate applications on primary parasites of western spruce budworm larvae, and other nontarget organisms (including several species of small mammals, birds, grouse, fish), and fish habitat.

In 1968, another pilot test was conducted in two areas within the Blackfoot River Drainage east of Missoula, Montana. Objectives of this test were:

a. To determine if mexacarbate applied at 1 ounce a.i./1 pt carrier/acre (28.35 g a.i./473.16 ml/0.404 ha) could effectively suppress western spruce budworm larval populations.

b. To test a nitrogen-pressurized spray system for applying insecticides.[2]

c. To apply the process of atmospheric transport and diffusion to cover the target areas.

[1]This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

[2]The nitrogen-pressured spray system was used to break up the insecticide spray mass into small droplets. It proved to be ineffective as the spray cloud could not be delivered into the target areas and this resulted in poor coverage.

Some results of these pilot tests in 1966 and 1968 have been published or summarized. Descriptions of the operational phases were summarized by Honing (1968) for the 1966 test, and by McGregor and Dewey (1968) for the 1968 test. Relationships between spray distribution, spray droplet size, and budworm mortality were described in a series of articles (Himel and Moore 1967; Himel 1969a; Himel and Moore 1969; Himel 1969b; and Buffam and others 1967). The effects of mexacarbate applications on nontarget organisms have been described for small mammals and birds (Pillmore and others 1971), for blue grouse (Mussehl and Schladweiler 1969), and for aquatic organisms (Graham and Gould 1967). This information and similar findings from other tests and studies provided the supportive base for the subsequent registration of mexacarbate with the U.S. Environmental Protection Agency (EPA) for the control of spruce budworms, *Choristoneura* sp. The studies reported here attempted to discern the effects of various mexacarbate treatments on major parasites of budworm larvae immediately following spraying and for 2 years thereafter.

Although at this writing mexacarbate is registered for budworm suppression, its manufacture has been discontinued. Nevertheless, we believe the effects of mexacarbate treatments on budworm parasites merits publication for the following reasons:

a. The chemical structure and insecticidal properties of mexacarbate closely resemble those of aminocarb (Matacil), another carbamate insecticide (Lyon 1976, Randall 1976). The studies reported here for mexacarbate have relevance for aminocarb. Aminocarb has replaced mexacarbate for control of the spruce budworm in Canada and may be registered in the United States.

b. These studies provide the basic data to describe the interaction of an insecticide with the host insect and its parasites. Results of these studies will be useful to those scientists who will be asked to develop an integrated pest management program for the western spruce budworm.

This paper describes the 1965, 1966, and 1968 mexacarbate applications and the 2 years of population sampling to determine amount of parasitism following treatments—a total of 6 years of field study (1965-1970).

MATERIALS AND METHODS

Study Areas and Treatments

All mexacarbate applications for these studies were made in budworm infested forests in Montana. These forests were largely a mixture of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco); Engelmann spruce (*Picea engelmanii* Parry); subalpine fir (*Abies lasiocarpa* [Hook.]); and grand fir (*A. grandis* [Dougl.] Lindl.). Ponderosa pine (*Pinus ponderosa* [Laws.]), a nonhost tree, occurred in substantial numbers on the dry, exposed sites. Douglas-fir was the most common host tree present.

The 1965 and 1966 mexacarbate applications were made in various drainages to the Bitterroot River in the Bitterroot National Forest. The 1965 tests occurred within four areas, each about 100 acres (40.5 ha), in the west fork of the Bitterroot River. Mexacarbate was aerially applied to budworm infested trees in Tough Creek at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 l/0.404 ha). Naled, an organophosphate insecticide, was applied in a low-volume concentrate of ethylene glycol at the rate of 0.41 lb a.i./0.82 pt/acre (185.97 g a.i./0.388 l/0.404 ha) to budworm infested trees in Mud Creek. Two drainages, One-Two Creek and Blue Joint Creek, served as checks. Budworm larval populations were sampled on 184 trees divided among the four drainages. The same trees were used throughout the 3-year study period. In 1965, budworm populations were sampled twice, 24 hours before treatment and again 7 days later. An extension pole pruner with a collecting bag attached just below the cutting head was used to cut two 15-inch (38-cm) branches from each crown third of each of the study trees. A total of six branches were cut from each study tree for each sampling period during 1965, 1966, and 1967. In 1966 and 1967, populations on study trees were sampled only once. Population sampling for all 3 years occurred when most budworms were in 5th and 6th instars, the age at which they are most exposed. Younger and smaller budworms are hidden by foliage or are mining the buds.

The 1966 tests were conducted on larger study areas within the Bitterroot River drainages. Mexacarbate was aerially applied at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 l/0.404 ha) to budworm infested trees in Trapper Creek, an approximate 5000-acre (2020-ha) drainage on the West Fork of the Bitterroot River, 11 miles southwest of Darby, Montana. The treatment was replicated on a 2000-acre (808.0-ha) infested stand in Laird Creek in the East Fork of the Bitterroot River. Two drainages—Violet Creek in the West Fork, and Andrews Creek in the East Fork of the Bitterroot River—served as check areas. Budworm populations were sampled 24 hours before treatment and again 5 and 10 days later using the same sampling procedures described for the 1965 tests. In 1967, populations were sampled only once. Because of limitations of personnel and field laboratory space, the parasite studies were done with budworm collected from 120 trees in the Trapper Creek drainage and 55 trees in the Violet Creek drainage.

The 1968 tests were conducted on budworm infested forests in two areas within the Blackfoot River drainage east of Missoula, Montana. Mexacarbate was aerially applied to 2912 acres (1176.4 ha) in the Burnt Fork of Belmont Creek and to 3168 acres (1279.9 ha) in Chamberlain Creek. A third area, located 20 miles (32.2 km) west of Chamberlain Creek and 12 miles (19.3 km) south of Belmont Creek, served as a check area. The insecticide formulation was mixed with Freon 12 at a 1:1 ratio and expelled from a nitrogen-pressurized spray system to produce a droplet spectrum having a volume median diameter (VMD)[3] of 60μ (U.S. Forest Service 1972). The aerial application technique was based on the concept of atmospheric transport and diffusion which uses the natural air movements in the drainage to disseminate droplets throughout the target area (Parker 1967).

In 1968, budworm populations were sampled 2 and 3 days before treatment by cutting four 15-inch (38-cm) branches from the midcrown of the study trees, and again 4 days after treatment with sixteen 15-inch (38-cm) branches cut from the midcrown of the study trees. In 1969 and 1970, budworm populations were sampled only once using four 15-inch (38-cm) branches from the midcrown of the study trees. Sampling for all 3 years was done when the majority of the budworm were 5th and 6th instars, and the same 40 trees in each area were sampled during the 3-year study period. The change in sampling procedures for the 1968 tests followed analyses of the 1965-1967 budworm sampling data which indicated that budworm population densities on branches from the midcrown of study trees were the approximate average densities for the entire tree crown. The data analyses also indicated that four branches per tree were a sufficient sample in order to be within a 10 percent sampling error for the expected prespray population levels, and that 16 branches would be required for the anticipated postspray population levels in order to be within a 10 percent sampling error.

[3]The theoretical center of the spray droplet size spectrum, i.e., half of the spray mass is in droplets larger than the VMD and half in droplets smaller than the VMD.

Laboratory Procedures

All sample branches with their resident insects were transferred to polyethylene bags and coded for study area, plot, tree, and crown level. Samples were placed in a walk-in refrigerator held at 40° to 45°F (4.44° to 7.22°C) and stored overnight. All insects were removed from the sample branches and bags the following day, separated by species, and counted at the field laboratory. Buds or shoots on each sample branch were counted and the length and width of each branch recorded.

All budworm larvae found in each sample were placed for rearing into 100-by-25 mm plastic petri dishes containing artificial diet (Lyon and others 1972). Ten larvae were placed in a dish. Dishes were examined periodically and diet replaced as needed. Nonparasitized larvae completed their development and adult moths emerged in the petri dishes. All budworms completing development were recorded. Mature parasites emerging from larvae were removed from the petri dishes and placed into gelatin capsules. Larvae and pupae from which neither adults nor parasites emerged were dissected for parasites. The parasites were first identified by using a key (Wilson and Bean 1964) and then by comparing them with identified specimens obtained from Colorado and Minnesota collections. The incidence of parasitism of budworm populations was determined by recording number of parasites that emerged from larvae rearings or were discovered by dissection, and was expressed as a ratio of number of parasites per 100 budworm larvae. The words "incidence of parasitism" and "parasitism" are used interchangeably in the text and refer to the ratio of parasites to budworm larvae.

RESULTS AND DISCUSSION

The 1965 Tests

Mexacarbate applied at the rate of 0.15 lb/a.i./gal/acre (68.04 g a.i./3.785 l/0.404 ha) was more effective (99 percent confidence level) than naled applied at the rate of 0.41 lb a.i./0.82 pt/acre (185.97 g a.i./0.399 l/0.404 ha) in suppressing budworm populations in 1965 field tests (*table 1*). In 1966, however, budworm populations began declining in study areas from unknown causes. Nevertheless, in 1966, population densities in the mexacarbate-treated area (Tough Creek) remained significantly lower (at the 95 percent confidence level) than population densities in the other three areas. By 1967, the last year of budworm sampling, population densities in one of the check areas (Blue Creek) had declined to the level of populations in Tough Creek, and these populations were significantly lower than those in the other two areas.

The 1965 insecticide treatments appeared to have different effects on the various groups of parasites of the western spruce budworm. No lasting effects were observed on the two overwintering parasites—the braconid *Apanteles fumiferanae* Viereck and the ichneumonid *Glypta fumiferanae* Viereck. Parasitism by *A. fumiferanae* increased significantly (at the 99 percent confidence level) in the 1965 posttreatment budworm population in the mexacarbate treated area, whereas, no significant difference in parasitism by *A. fumiferanae* was found between the pretreatment, and post-treatment budworm populations among the other study areas (*table 2*). Parasitism by *A. fumiferanae* returned to the 1965 pretreatment levels by 1966, and no *A. fumiferanae* were recovered from either Tough Creek or Blue Joint Creek in 1967. Because of the low budworm population densities in these two areas (*table 1*) in 1967, it is not surprising that *A. fumiferanae* were difficult to detect or recover. Seven *A. fumiferanae,* however, were recovered in 1967 from budworm populations collected from Mud Creek (*table 2*).

Parasitism by *G. fumiferanae* was similar before and after treatments in 1965 in all four areas (*table 2*). It declined in 1966 at Mud Creek, the naled-treated area, and at Blue Joint, a check area, but sparse host populations in most of the study areas the following year prevented evaluation of parasitism by *G. fumiferanae,* except to show that it was present (*table 2*).

Table 1—*Trees sampled and estimates of western spruce budworm (Choristoneura occidentalis Freeman) larval populations before and after 1965 insecticide treatments, and for 2 years following in the study areas*

Treatment and study area	Trees	1965 Prespray estimate	1965 Postspray estimate	1966 Estimate (1 year)	1967 Estimate (2 years)
		Larvae per 1000 square inches branch surface[1]			
Mexacarbate:					
Tough Creek	56	[2]37.8[3](3.3)	[4]4.1 (0.9)	[5]2.44 (0.30)	0.42 (0.08)
Naled:					
Mud Creek	43	43.8 (4.5)	23.0 (3.1)	8.87 (1.02)	1.04 (0.27)
Controls:					
One-Two Creek	45	44.1 (3.7)	32.7 (2.6)	8.16 (0.85)	2.52 (0.32)
Blue Joint Creek	40	33.0 (3.5)	22.4 (2.5)	5.64 (0.56)	0.54 (0.13)

[1]*C. occidentalis* larvae per 1000 square inches (6451.6 square cm) branch surface.

[2]Prespray population estimates among the study areas are not significantly different at the 95 percent confidence level, according to t-tests.

[3]Values in parentheses are standard errors (SE).

[4]The estimate is significantly different at the 99 percent level from the postspray estimates of the other study areas.

[5]The estimate is significantly different at the 95 percent level from those in the other study areas.

Table 2—*Estimates of parasitism of western spruce budworm (Choristoneura occidentalis Freeman) by the early larval parasites, Apanteles fumiferanae and Glypta fumiferanae, and late larval, pupal parasites, Phaeogenes hariolus and tachinids, before and after 1965 insecticide treatments, and for 2 years following in the study areas.*

Treatment and study area	1965				1966		1967	
	Prespray estimate[1,2]	Parasites reared	Postspray estimate[1,2]	Parasites reared	Estimate[1] (1 year)	Parasites reared	Estimate[1] (2 years)	Parasites reared
	Apanteles fumiferanae							
Mexacarbate:								
Tough Creek	[4]5.46 [3](0.59)	124	[5]15.10 (2.70)	29	[4]4.46 (1.60)	7	— —	—
Naled:								
Mud Creek	3.42 (0.59)	56	1.92 (0.52)	18	2.63 (0.83)	11	8.25 (3.59)	7
Check:								
One-Two Creek	3.55 (0.57)	75	4.18 (0.73)	56	2.58 (0.80)	12	1.90 (1.80)	3
Check:								
Blue Joint Creek	3.75 (0.68)	44	2.55 (0.61)	22	1.21 (0.70)	3	— —	—
	Glypta fumiferanae							
Mexacarbate:								
Tough Creek	[4]8.46 (0.77)	192	5.73 (1.41)	11	8.92 (2.56)	14	[4]7.41 (5.19)	2
Naled:								
Mud Creek	9.46 (0.94)	155	8.65 (1.03)	81	2.87 (1.03)	12	4.71 (2.42)	4
Check:								
One-Two Creek	10.76 (1.02)	277	9.85 (0.97)	132	13.09 (2.25)	61	6.96 (1.98)	11
Check:								
Blue Joint Creek	8.00 (1.07)	94	7.64 (1.09)	66	2.02 (0.90)	5	7.69 (4.80)	2
	Tachinids							
Mexacarbate:								
Tough Creek	1.15 (0.33)	26	0.52 (0.53)	1	— —	—	3.70 (3.73)	1
Naled:								
Mud Creek	0.67 (0.24)	11	0.64 (0.26)	6	0.24 (0.24)	1	3.53 (2.40)	3
Check:								
One-Two Creek	3.79 (0.59)	80	4.49 (0.67)	60	2.79 (0.82)	13	— —	—
Check:								
Blue Joint Creek	8.26 (1.03)	97	5.90 (0.90)	51	3.24 (1.28)	8	— —	—
	Phaeogenes hariolus							
Mexacarbate:								
Tough Creek	1.32 (0.32)	30	[5]11.46 (3.25)	22	— —	—	— —	—
Naled:								
Mud Creek	0.55 (0.23)	9	0.75 (0.32)	7	— —	—	— —	—
Check:								
One-Two Creek	0.28 (0.11)	6	[5]2.16 (0.43)	29	0.64 (0.37)	3	— —	—
Check:								
Blue Joint Creek	0.60 (0.25)	7	[6]3.70 (0.86)	32	— —	—	— —	—

[1]Parasitism is expressed as the number of parasites per 100 budworm *(C. occidentalis)*.
[2]Estimate from populations sampled 24 hours before treatment; postspray estimate from populations sampled 7 days after treatment.
[3]Values in parentheses are standard errors (SE).
[4]Sample period estimates for the incidence of parasitism among the study areas not significantly different at the 95 percent confidence level, according to t-tests.
[5]Significantly different from the prespray estimate at the 99 percent confidence level, according to t-tests.
[6]Significantly different from the prespray estimate at the 95 percent confidence level, according to t-tests.

The incidence of parasitism of western budworm larvae by tachinids was highly variable among the study areas before the treatments and, after the treatments, was much lower in the insecticide-treated areas than in the check areas. Tachinids seemed to be affected adversely by mexacarbate (*table 2*). This situation is suggested by the few reared from posttreatment budworm collections in 1965 and 1966, particularly in the mexacarbate-treated area, and also by the decline in parasitism in the treated areas in 1965 and 1966 compared with the relative stability of parasitism in the check areas. Tachinids were attacking budworm larvae at treatment time and, therefore, were more vulnerable to the insecticides than were *A. fumiferanae* and *G. fumiferanae*. These two overwintering parasites attacked 1st and 2nd instar budworm larvae the preceding fall, overwintered in the larvae, and had not yet emerged at treatment time. No tachinids were recovered in 1966 from budworm larvae collected from the 1965 mexacarbate-treated area (Tough Creek), and only one was recovered from the naled-treated area (Mud Creek). Although parasitism by tachinids differed (95 percent level) between the check areas in 1965, it was similar in 1966. Few tachinids were recovered from all areas in 1966, and only four tachinids were recovered from the four study areas in 1967—three from Mud Creek and one from Tough Creek. None was recovered from any of the check areas which contained the higher number of tachinids the previous 2 years.

Another parasite, *Phaeogenes hariolus* (Cresson), attacked budworm larvae at the time treatments were applied. A significant increase in parasitism by *P. hariolus* in the postspray budworm populations occurred in three areas (*table 2*). The increase was statistically significant at the 99 percent confidence level in Tough Creek and One-Two Creek, and at the 95 percent level in Blue Joint. No significant increase in parasitism by *P. hariolus* was found in Mud Creek. Only three *P. hariolus* were recovered from budworm populations in 1966; none was recovered in 1967.

Both tachinids and *P. hariolus* were flying and attacking budworm larvae at the time of treatment, but only the tachinids appeared to have been harmed by mexacarbate. Apparently *P. hariolus* was not affected, and its parasitism of budworm larvae increased significantly in the mexacarbate-treated area and in the check areas. But *P. hariolus* was practically absent from all four areas in the 2 years following spraying.

The 1966 Tests

Mexacarbate applied, at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 1/0.404 ha) severely suppressed budworm populations in Trapper Creek—up to 95 percent 5 days after treatment *(table 3)*. Mortality remained essentially the same by the 10-day postspray sampling period. Budworm mortality in the Violet Creek check area was 46 percent by 5 days and 64 percent by 10 days postspray *(table 3)*. Prespray budworm populations were similar in Trapper and Violet

Table 3—*Estimated population densities of western spruce budworm (Choristoneura occidentalis Freeman) before and after 1966 mexacarbate treatments, percent mortality following treatments, and 1967 estimated population densities*

Study area and treatment	Trees	1966 Prespray estimate[1]	1966 (5 days) Postspray estimate[1]	1966 (5 days) Mortality	1966 (10 days) Postspray estimate[1]	1966 (10 days) Mortality	1967 Estimate[1] (1 year)
				Percent		Percent	
Trapper Creek (Mexacarbate)	120	27.90 [2](1.42)	[3]1.36 (0.17)	95.14 (0.67)	[3]1.20 (0.18)	94.24 (0.99)	4.51 (0.44)
Violet Creek (Check)	55	22.28 (1.45)	11.87 (0.93)	46.03 (3.49)	6.82 (0.89)	64.00 (4.06)	6.13 (0.57)

[1]Number of budworm (*C. occidentalis*) per 1000 square inches (6451.6 square cm) branch surface.
[2]Values in parentheses are standard errors (SE).
[3]Population density of mexacarbate-treated area significantly different from that in the check area at 99 percent confidence level.

Creeks but were significantly different (99 percent confidence level) at the 5- and 10-day postspray samples. This difference in budworm population densities between the two areas in 1967 was not significant *(table 3)*.

Parasitism of budworm populations by *A. fumiferanae* and *G. fumiferanae* increased after spray treatment in Trapper Creek and also in the check area, Violet Creek, but much more so in Trapper Creek (*table 4*). Parasitism by *A. fumiferanae* was similar in both areas before treatment but was significantly greater in Trapper Creek (99 percent confidence level) than in the check area within 5 days after the mexacarbate application (*table 4*). The following year, however, parasitism by *A. fumiferanae* returned to about its 1966 prespray level and was again similar for both areas (*table 4*).

Prespray parasitism of budworm by *G. fumiferanae* was significantly higher (99 percent confidence level) in Violet Creek than in Trapper Creek (*table 4*). But the increase (significant at the 99 percent confidence level) in parasitism by *G. fumiferanae* following treatment resulted in approximately similar levels of parasitism in the study areas by the 5-day postspray population sample. In 1967, parasitism by *G. fumiferanae* returned to its 1966 prespray level in Trapper Creek, but was lower in Violet Creek (*table 4*).

Parasitism by *P. hariolus* and *Mesochorus* sp. also increased after the mexacarbate treatment in Trapper Creek but not at a significant level (*table 4*). These parasites were attacking large budworm larvae during and after mexacarbate application. Some of these parasites, therefore, were exposed to the insecticide, but there is no evidence that they were affected by it in 1966. Only two *Mesochorus* sp., however, were recovered the following year.

The incidence of tachinids in the budworm populations also increased after treatment in Trapper Creek (95 percent confidence level) and in the check area (99 percent confidence level) (*table 4*). These parasites also were in the midst of their attack period during and after treatment and, therefore, some were exposed to the insecticide. Nevertheless, in contrast to the 1965 studies, we found no difference in parasitism by tachinids between treatment and check areas in 1966 and 1967. Except for the postspray samples from Trapper Creek, the numbers of tachinids reared from budworm larvae from the two areas were similar (*table 4*).

The 1968 Tests

Mexacarbate applied at the rate of 1 oz a.i./pt/acre (28.35 g a.i./473.16 ml/0.404 ha) reduced budworm populations about 71 percent in Belmont Creek and 53 percent in Chamberlain Creek (*table 5*). Budworm populations in a check area declined only about 34 percent during the treatment period (*table 5*). These treatments were considered failures because they did not succeed in adequately suppressing budworm population; i.e., treatments did not achieve at least 90 percent mortality. A review of the decisions and events that occurred before and during these tests suggests that mexacarbate was applied in marginal dosage, and in inadequate volume and application for maximum area coverage and field effectiveness in the 1968 tests.

The 1965 and 1966 field tests of mexacarbate showed that mexacarbate applied at the rate of 0.15 lb a.i. (2.4 ounces)/acre, (68.04 g a.i./0.404 ha) can effectively suppress budworm populations. Laboratory tests have indicated that mexacarbate will cause 90 percent mortality of 5th and 6th instars at approximately 0.49 to 0.74 oz/acre (13.9 to 21.0 g/0.404 ha) (Robertson and others 1976). There is a strong possibility that the dosage of 1 oz a.i./acre (28.35 g a.i./0.404 ha) was marginal for killing large budworm larvae. Laboratory tests also showed the LD_{90} dosage required to kill mature 6th instars (body weight > 110 mg) ranged from 1.9 to 11 oz/acre (53.9 to 311.9 g/0.404 ha). The strong statistical difference between the LD_{90} dosages for small and mature 6th instars emphasizes the importance of timing spray applications before mature 6th instar larvae appear in the population (Robertson and others 1976).

Also, a given amount of mexacarbate applied at 1 gal formulation per acre (3.785 1/0.404 ha) would normally result in better coverage of target areas than an equal amount of mexacarbate applied at 1 pt formulation per acre (0.47 1/0.404 ha) because of the greater volume being applied. Kromekote cards used in the 1965 and 1966 tests to trace dispersion of the nonaerosal portion of the insecticide in the target areas showed an average of 50.38 ± 34.70 (95 percent probability level) spray droplets (those $> 50\mu$) per square centimeter for the 1966 test. Given the areal coverage problems of aerial application of insecticides, a pint per acre would produce a substantially lower spray droplet density average than would 1 gallon per acre.

Table 4—*Estimates of parasitism of western spruce budworm (Choristoneura occidentalis Freeman) populations by the five most numerous parasites, and number of parasites reared from collections of the host insect, before and after mexacarbate treatments in 1966 and 1967*

Study area and treatment	1966 Prespray estimate[1]	1966 Parasites reared	1966 Postspray estimate[1]	1966 Parasites reared	1967 Estimate[1] (1 year)	1967 Parasites reared
Apanteles fumiferanae						
Trapper Creek (Mexacarbate)	2.15 [2](0.29)	79	[3]14.47 (2.61)	34	1.24 (0.47)	7
Violet Creek (Check)	3.10 (0.47)	53	6.16 (1.11)	53	2.23 (0.75)	9
Glypta fumiferanae						
Trapper Creek (Mexacarbate)	3.49 (0.41)	128	[3]20.00 (3.05)	47	3.72 (0.87)	21
Violet Creek (Check)	[4]9.75 (0.96)	167	[5]15.93 (1.59)	137	4.95 (1.09)	20
Phaeogenes hariolus						
Trapper Creek (Mexacarbate)	0.16 (0.08)	6	2.13 (0.93)	5	— —	—
Violet Creek (Check)	— —	—	0.93 (0.32)	8	— —	—
Mesochorus sp.						
Trapper Creek (Mexacarbate)	0.05 (0.04)	2	1.70 (0.98)	4	0.35 (0.25)	2
Violet Creek (Check)	0.06 (0.06)	1	0.47 (0.23)	4	— —	—
Tachinids						
Trapper Creek (Mexacarbate)	1.34 (0.23)	49	[5]6.38 (1.91)	15	0.71 (0.34)	4
Violet Creek (Check)	2.75 (0.58)	47	[3]9.65 (1.46)	83	0.74 (0.41)	3

[1]Parasitism is expressed as the number of parasites per 100 budworm *(C. occidentalis)*.
[2]Values in parentheses are standard errors (SE).
[3]Significantly different from the prespray estimate at the 99 percent confidence level, according to t-tests.
[4]Significantly different from the prespray estimate of Trapper Creek at the 99 percent confidence level, according to t-tests.
[5]Significantly different from the prespray estimate at the 95 percent confidence level, according to t-tests.

Table 5—*Trees sampled and estimates of western spruce budworm (Choristoneura occidentalis Freeman) populations at the large larval stage before and after 1968 mexacarbate treatments, percent mortality following treatments, and 1969 and 1970 population estimates*

Study area	Trees	1968 Prespray estimate[1]		1968 Postspray estimate[1]		1968 Mortality		1969 Estimate (1 year)		1970 Estimate (2 years)	
						Percent					
Belmont	40	37.66	[2](34.98)	10.67	(9.95)	71.66	(26.88)	22.40	(1.77)	[3]37.62	(1.91)
Chamberlain	40	54.99	(38.24)	25.81	(18.34)	53.06	(53.24)	31.05	(2.77)	[4]44.65	(2.67)
Check	40	24.06	(26.95)	15.87	(15.34)	34.04	(58.12)	—	—	—	—

[1]Number of western spruce budworm (*C. occidentalis*) per 1000 square inches (6451.6 square cm) branch surface area.
[2]Values in parentheses are standard errors (SE).
[3]Significant difference compared to preceding sampling period at 99 percent level of confidence.
[4]Significant difference compared to preceding sampling period at 95 percent level of confidence.

In addition, a new aerial technique, applying the concept of atmospheric transport and diffusion of insecticide spray droplets, was used in the 1968 tests. Instead of the sequential swathing technique used in the earlier tests, these applications were made along ridges and were tailored to use the normal air patterns existing in the test drainages to transport the small spray droplets throughout the forest. A weather front moved through the area just before spray application and affected local air drainage patterns. By applying a technique based on conditions that existed before the passage of the weather front, we did not achieve the desired coverage under the new conditions.

Spray dispersion and droplet densities were not measured in treatment areas, because the 1966 tests showed that Kromekote cards could not clearly show spray droplets smaller than 50μ, the more effective portion of the droplet spectrum (Himel and Moore 1967). We had no way, therefore, to determine the dispersion of any part of the droplet spectrum. Observations made in Chamberlain during treatment indicated that the small droplets never reached understory trees (15 to 20 ft [4.6 to 6.1 m] high). Many live larvae were found on trees throughout the area in late afternoon after treatment and during the postspray sample.

In 1969, budworm populations on the check area declined beyond the capabilities of our sampling effort to detect them. The area was not reexamined in 1970. Budworm populations on the treated areas were moderately high in 1969, and increased significantly in 1970 (*table 5*).

PARASITISM IN THE 1968 TESTS

Although the 1968 treatments did not achieve the degree of suppression of the budworm population desired, they did provide some unexpected information on parasites. Parasitism of budworm populations by all groups of parasites tended to increase during and after treatments in all areas but this increase was significant only in Chamberlain. The total number of parasites reared from the postspray budworm collections far exceeded the number reared from the prespray collections. This situation was especially pronounced in the Chamberlain area which had only 53 percent larval mortality from mexacarbate treatments compared with the Belmont area which had about 71 percent larval mortality.

The overwintering parasites, *G. fumiferanae* and *A. fumiferanae*, and the late larval, pupal parasites—the tachinids—were mainly responsible for the significant increase in parasitism of budworm populations in Chamberlain sampled 4 days after treatments (*table 6*). Parasitism by *A. fumiferanae* increased significantly (at the 95 percent confidence level) in Chamberlain within 4 days after treatment and remained significantly higher than the pretreatment level for the following 2 years. Parasitism by *G. fumiferanae* remained significantly higher than the pretreatment level for 1 year and returned to the pretreatment level in 1970 (*table 6*). Tachinids and *Mesochorus* sp. were attacking budworm larvae at the time mexacarbate was applied. Parasitism by tachinids increased significantly immediately after treatment, but declined to pretreatment levels the following year (*table 6*).

The large number of parasites reared during the 4-day postspray sample in Chamberlain was particularly noteworthy (*table 6*). Apparently the relatively high survival of budworm from the mexacarbate treatment in Chamberlain (47 percent survival), relative to Belmont (29 percent survival), also resulted in a disproportionately higher survival of parasitized larvae in Chamberlain. The studies of mexacarbate treatment on budworm reported here and earlier (Williams and others 1969) and of other insecticide treatments on spruce budworm, *Choristoneura fumiferanae* (Clem.) populations (MacDonald 1959) have shown an increase in parasitism of budworm surviving insecticide treatments. This increase may be explained by the lower exposure of the relatively inactive, moribund parasitized larvae to random mortality factors, such as insecticide spray droplets, resulting in a higher proportionate survival of parasitized larvae over healthy, active nonparasitized larvae.

Table 6—*Estimates of parasitism of western spruce budworm (Choristoneura occidentalis Freeman) populations by the four most numerous parasites, and number of parasites reared from collections of the host insect, before and after 1968 mexacarbate treatments, and for 2 years following in the study areas*

Study area	1968				1969		1970	
	Prespray estimate[1]	Parasites reared	Postspray estimate[1]	Parasites reared	Estimate[1] (1 year)	Parasites reared	Estimate[1] (2 years)	Parasites reared
				Apanteles fumiferanae				
Belmont	5.47[2] (0.93)	49	6.61 (0.79)	79	6.61 (1.02)	83	7.27 (1.39)	85
Chamberlain	3.28 (0.44)	43	[3]6.14 (0.71)	221	[3]6.24 (0.75)	175	[3]8.88 (0.79)	152
Check	4.49 (0.89)	35	5.83 (0.78)	95	— —	—	— —	—
				Glypta fumiferanae				
Belmont	11.84 (1.77)	106	14.21 (1.68)	170	10.43 (1.13)	131	5.22 (0.79)	61
Chamberlain	7.56 (0.87)	99	[3]13.94 (1.04)	502	[3]11.81 (0.73)	331	6.78 (0.91)	116
Check	5.90 (0.82)	46	9.69 (1.15)	158	— —	—	— —	—
				Tachinids				
Belmont	0.78 (0.29)	7	2.09 (0.67)	25	0.32 (0.16)	4	0.17 (0.12)	2
Chamberlain	0.92 (0.29)	12	[3]2.94 (0.48)	106	0.43 (0.15)	12	0.29 (0.15)	5
Check	— —	—	0.18 (0.10)	3	— —	—	— —	—
				Mesochorus sp.				
Belmont	0.22 (0.22)	2	0.84 (0.37)	10	0.24 (0.14)	2	0.09 (0.08)	1
Chamberlain	0.08 (0.08)	1	0.19 (0.07)	7	0.29 (0.13)	8	0.06 (0.06)	1
Check	0.26 (0.24)	2	0.55 (0.28)	9	— —	—	— —	—

[1]Parasitism is expressed as the number of parasites per 100 budworm (*C. occidentalis*).
[2]Values in parentheses are standard errors (SE).
[3]Significantly different from the prespray level at the 95 percent confidence level.

We believe the above explanation is particularly pertinent for budworm larvae parasitized by *A. fumiferanae* and *G. fumiferanae.* These parasites attack the 1st and 2nd instars and, except for some early emergence of *A. fumiferanae* from the 4th instar, their progeny emerge from 5th and 6th instars. A parasitized 5th-6th instar budworm containing a fully developed parasite about to emerge is usually inactive and moribund. These larvae probably would not be as exposed to insecticide droplets and residues as normal, highly mobile, actively feeding 5th-6th instars. The insecticide treatments were applied at the time most of the budworm populations were in 5th and 6th instars.

Because tachinids and other late larval, pupal parasites attacked budworm during and after treatments, high proportionate survival of parasitized larvae does not explain the increase in parasitism of budworm by these parasites. We would not expect newly parasitized budworm larvae to be as inactive and moribund as those containing the fully developed larvae of *A. fumiferanae* and *G. fumiferanae.* The exposure of newly parasitized budworm, therefore, should be similar to that of healthy nonparasitized budworm larvae. Parasitization of budworm larvae after treatment probably contributed substantially to the increase in parasitism by late larval, pupal parasites.

Our studies suggest that high proportionate survival of parasitized larvae, in terms of percentage of the total host population of budworm larvae and in actual numbers of surviving parasites, results when an insecticide kills a relatively low percentage of the host population. As more and more of the total budworm larval population is killed by the insecticide, increasing numbers of parasitized budworm larvae are also killed. This situation results in a still higher proportionate survival of parasitized larvae, relative to nonparasitized larvae, but lower numbers of parasitized larvae survive. We observed lower survival of parasitized larvae in the 1965 and 1966 tests in which over 90 percent of the budworm populations were killed.

In the 1968 studies, however, large numbers of parasitized budworm larvae survived treatments. As a result, a substantial increase occurred in the numbers of parasites (*A. fumiferanae, G. fumiferanae*, and tachinids) reared from posttreatment collections of budworm larvae, particularly those from Chamberlain in 1968, compared to those reared in the 1965 and 1966 studies (*table 6*). Consequently, large numbers of parasites were available in Chamberlain during the summer of 1968 to attack the next generation of budworm larvae. We believe that this situation was responsible for maintaining the high incidence of parasitism by *G. fumiferanae* and *A. fumiferanae* for 1 and 2 years in posttreatment budworm populations in Chamberlain. Furthermore, we believe that high parasite survival is due directly to the relatively low insecticide-induced mortality of budworm larvae obtained in the 1968 tests, compared to the high mortality obtained in the 1965 and 1966 tests.

Bartlett (1963), in discussing guidelines in development of integrated programs, suggests that any differential toxicity response to the insecticide favoring the natural enemy over the pest, can usually be accentuated by a decrease in the field dosage to a point where somewhat less than 100 percent of the pest is destroyed. Field data from all parasite studies of mexacarbate treatments on western spruce budworm populations reported here support this statement. More specifically, results from the 1968 treatments suggest that parasite survival is enhanced even more under insecticide treatments when less than 70 percent of the host insect is destroyed. In this situation, a large reservoir of parasites is available to parasitize the host insect the following year. These 1968 treatment results in the Chamberlain area further suggest that parasitism and parasite abundance may even be increased for a few years as a result of insecticide treatment.

Reports of various pesticide programs for control of agricultural insect pests have frequently described the virtual elimination of the natural enemies of the pests, followed by a resurgence of the pest populations—often to higher levels than before pesticide treatments (Van den Bosch 1970, Kilgore and Doutt 1967, and Pickett and MacPhee 1965). Studies of the effects of pesticides on forest insects, mainly the spruce budworm and its parasites, however, have shown severe suppression of host populations and increased parasitism after treatment.

One of the first studies reporting high proportionate survival of parasitized budworm larvae (Eaton and others 1949) mentioned that 70 percent of the surviving budworm from the plots near Heppner, Oregon, treated with DDT in 1948, were small parasitized larvae that escaped the spray probably through failure to travel and feed. An unpublished report on the effects of DDT applied in 1949 and 1950 to budworm-infested forests in Washington and Oregon concluded that *Campoplex* sp. and the two overwintering parasites, *A. fumiferanae* and *G. fumiferanae*, survived aerial sprays of DDT in sufficient numbers to exert even greater natural control of the budworm than before spraying.[4]

Studies in Eastern Canada on the effects of DDT on spruce budworm *Choristoneura fumiferanae* (Clemens) and its two overwintering parasites in New Brunswick described a distinct tendency toward increased parasitism by *A. fumiferanae* and decreasing parasitism by *G. fumiferanae* in succeeding postspray budworm generations (MacDonald 1959). These are the only parasites present in the 3rd and 4th instars, the budworm stages when spraying commences in Canada and, therefore, are the parasites most vulnerable to the insecticides. Higher proportionate survival of *A. fumiferanae* parasitized budworm and earlier emergence of *A. fumiferanae* from the hosts, in many cases before spraying, were the major reasons given for differences in parasitism between the parasites (MacDonald 1959).

Another series of studies on the effects of DDT applied in 1958 against the budworm in eastern Oregon reported good survival of *A. fumiferanae* and, to a lesser extent, *G. fumiferanae,* reared from survivors collected 10 or 11 days after spraying. Parasitism of small larvae 1 year after spraying was 7 to 14 percent higher than that in spring before spraying (Carolin and Coulter 1971). None of the common parasites which attack full-grown larvae, however, were reared from surviving budworm. Parasitism of these larvae increased dramatically the following year on some of the plots (Carolin and Coulter 1971).

Leonard and Simmons (1974) reported on the immediate effects of mexacarbate on the parasites of spruce budworm, *C. fumiferanae* (Clemens) in Aroostock County, Maine. Their data showed that pupal parasites—tachinids and *Ephialtes ontario* Cresson—were significantly lower in mexacarbate-treated areas than in untreated areas during the year of application. This difference indicates that mexacarbate applied when most of the budworm are 5th (of 6) instars may kill some adult parasites attacking late-stage budworm larvae and pupae. Pupal parasites that start attacking the late-stage larval instars a day or two after application of mexacarbate, however, would not be affected by this insecticide because its residual life is short, less than 2 days (Robertson and others 1976).

Adults of *A. fumiferanae* and *G. fumiferanae* are not normally exposed to spraying operations because their presence is synchronized with that of budworm moths, eggs, and the first and possibly the second budworm instar in hibernaculae (Blais 1977). Larvae of these parasites, however, are exposed to insecticides applied against 5th and 6th instar budworm in several ways. We would expect some who are still in budworm larvae that came in contact with lethal amounts of the insecticide to be killed. Our parasite rearings indicated that sublethal amounts of the insecticides to parasitized budworm larvae may have adversely affected emerging parasites, because a number of them had spun their cocoons and died. We had expected some of those who emerged during treatment to be killed, and the danger of exposure following treatment related to the residual life of the insecticide.

The exposure of the late larval, pupal parasites, e.g., *P. hariolus, Mesochorus* sp. and the tachinids, to insecticides applied against 5th and 6th instars of the budworm, is different from that of parasites that attack the young or early budworm instars. Adult late-larval parasites were flying and attacking budworm larvae before, during, and after treatment. Some of the adult parasites exposed to the treatments were killed. We found some evidence of this mortality in 1965 by the numbers of tachinids collected in drop cloths, and the number reared from the 1965 post-treatment collections of budworm larvae. The danger of exposure after treatment to the adult parasite and eventually to its progeny would be related to the residual life or persistence of the insecticide.

[4]W. K. Coulter. *Effects of aerial spraying upon parasites of the spruce budworm.* Talk given at Second Annual Meeting, Pacific Branch, Entomol. Soc. Amer., Bend, Oreg. June 22-24, 1954.

CONCLUSIONS

Aerially applied mexacarbate to 5th and 6th instars of western spruce budworm effectively controlled this insect pest to the extent of ≥ 90 percent mortality when the insecticide was applied at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 1/0.404 ha.). Mexacarbate applied aerially at the rate of 1 oz a.i./pt/acre (28.35 g a.i./473.16 ml/0.404 ha) reduced budworm populations (50 to 70 percent mortality) but treatments were considered failures because mortality of the budworm was < 90 percent. This latter dosage was successful, however, in that higher parasite survival provided unexpected information on several common parasites of the western spruce budworm.

The results of our studies suggest that parasite survival may be enhanced under conditions of moderate suppression of 5th and 6th instar budworm populations (50 to 70 percent mortality) by mexacarbate. A large reservoir of parasites is available to attack budworm larvae of the succeeding generation. And increased parasitism under these conditions may last for several years. These phenomena merit further investigation because they indicate compatible roles for insecticides and parasites in the control of budworm populations. Possibly nonpersistent insecticides can be used not only to reduce directly epidemic budworm populations, but also to increase the ratio of parasites to budworm, thereby enhancing parasite effectiveness in controlling budworm for several years after chemical treatment.

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☆ GPO 69

Williams, Carroll B., Jr., Patrick J. Shea, and Mark D. McGregor.
1979. **Effects of aerially applied mexacarbate on western spruce budworm larvae and their parasites in Montana.** Res. Paper PSW-144, 14 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

In tests on the Bitterroot National Forest, Montana, in 1965 and 1966, mexacarbate, aerially applied at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 1/0.404 ha), killed about 90 percent of the western spruce budworm (*Choristoneura occidentalis* Freeman) populations. More parasitized budworm larvae survived treatments than nonparasitized. *Apanteles fumiferanae* Viereck and *Glypta fumiferanae* Viereck—two overwintering parasites—and *Phaeogenes hariolus* (Cresson), *Mesochorus* sp., and tachinids—late larval, pupal parasites—increased following treatments. But parasites tended to return to pretreatment levels the next year. In 1968, mexacarbate, aerially applied at the rate of 1 oz a.i./pt/acre (28.35 g a.i./473.16 ml/0.404 ha), achieved 71 percent mortality in one area and 53 percent in another. *A. fumiferanae, G. fumiferanae,* and tachinids increased in the area of lowest budworm mortality, and parasitism by *A. fumiferanae* and *G. fumiferanae* remained significantly higher than the 1968 prespray level for from 1 to 2 years, respectively. The results suggest that mexacarbate may be used to moderately suppress populations of budworm larvae in order to increase the ratio of parasites to budworm.

Retrieval Terms: Insecticides; mexacarbate; naled; *Choristoneura occidentalis; Apanteles fumiferanae; Glypta fumiferanae; Phaeogenes hariolus; Mesochorus;* tachinids.

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In tests on the Bitterroot National Forest, Montana, in 1965 and 1966, mexacarbate, aerially applied at the rate of 0.15 lb a.i./gal/acre (68.04 g a.i./3.785 1/0.404 ha), killed about 90 percent of the western spruce budworm (*Choristoneura occidentalis* Freeman) populations. More parasitized budworm larvae survived treatments than nonparasitized. *Apanteles fumiferanae* Viereck and *Glypta fumiferanae* Viereck—two overwintering parasites—and *Phaeogenes hariolus* (Cresson), *Mesochorus* sp., and tachinids—late larval, pupal parasites—increased following treatments. But parasites tended to return to pretreatment levels the next year. In 1968, mexacarbate, aerially applied at the rate of 1 oz a.i./pt/acre (28.35 g a.i./473.16 ml/0.404 ha), achieved 71 percent mortality in one area and 53 percent in another. *A. fumiferanae, G. fumiferanae,* and tachinids increased in the area of lowest budworm mortality, and parasitism by *A. fumiferanae* and *G. fumiferanae* remained significantly higher than the 1968 prespray level for from 1 to 2 years, respectively. The results suggest that mexacarbate may be used to moderately suppress populations of budworm larvae in order to increase the ratio of parasites to budworm.

Retrieval Terms: Insecticides; mexacarbate; naled; *Choristoneura occidentalis; Apanteles fumiferanae; Glypta fumiferanae; Phaeogenes hariolus; Mesochorus;* tachinids.

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