AERIAL APPLICATION OF *Bacillus thuringiensis* AGAINST LARVAE OF THE Elm Spanworm AND Gypsy Moth AND EFFECTS ON PARASITOIDS OF THE GYPSY MOTH

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The cover photograph is by George Scheussler.

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Contents

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INTRODUCTION

Aerial spray tests were conducted in Connecticut during 1972 to evaluate two formulations of *Bacillus thuringiensis* Berliner against larvae of the gypsy moth, *Porthetria dispar* (L.), and the elm spanworm, *Ennomos subsignarius* (Hübner). These two insects were extremely abundant in the State during 1970 and 1971, and surveys suggested that they would be abundant again in 1972.

In past field tests, commercial preparations of *B. thuringiensis* based on the serotype I Berliner strain, applied from the air, have produced variable results and generally poor control of gypsy moth larvae (Doane and Hitchcock 1964; Lewis and Connola 1966). In 1970, a more potent isolate of *B. thuringiensis* belonging to serotype III was propagated and put into commercial production. Three new commercial formulations were developed. These were field-tested as ground sprays and found to be highly effective against larvae of the elm spanworm and moderately effective against gypsy moth larvae (Dunbar and Kaya 1972). Aerial spray tests conducted in 1971 by Secrest and McLane (1971) suggested that *B. thuringiensis* mixed with molasses was effective against gypsy moth larvae. These encouraging results led us to evaluate one of the new formulations as well as an experimental formulation as aerial sprays against gypsy moth and elm spanworm. The effects of the sprays on parasitoids of the gypsy moth were also evaluated.

APPLICATION METHODS AND MATERIALS

Plot description and markings

Test plots 30 acres in size (14 x 21 chains, 1 chain = 66 ft) were established in the Cockaponset State Forest (CSF) adjacent to Pattaconk Lake (Fig. 1) and in the Salmon River State Forest (SRSF) along Dickinson Creek (Fig. 2). These forests are typical of the cutover mixed deciduous woodland which covers much of Connecticut. The stand in each forest is 70 to 85 years old and is dominated by oaks. The terrain in both forests varied in elevation from 300-550 ft.

The vegetation in all plots in SRSF, with the exception of Plots 6 and 10, consists predominantly of white oak, *Quercus alba;* chestnut oak, *Q. prinus;* and northern red oak, *Q. rubra;* with some red maple, *Acer rubrum;* and black birch, *Betula lenta.* Plots 6 and 10 had more maple and birch than oak. The vegetation in plots in CSF consists of approximately 50% white oak, chestnut oak and

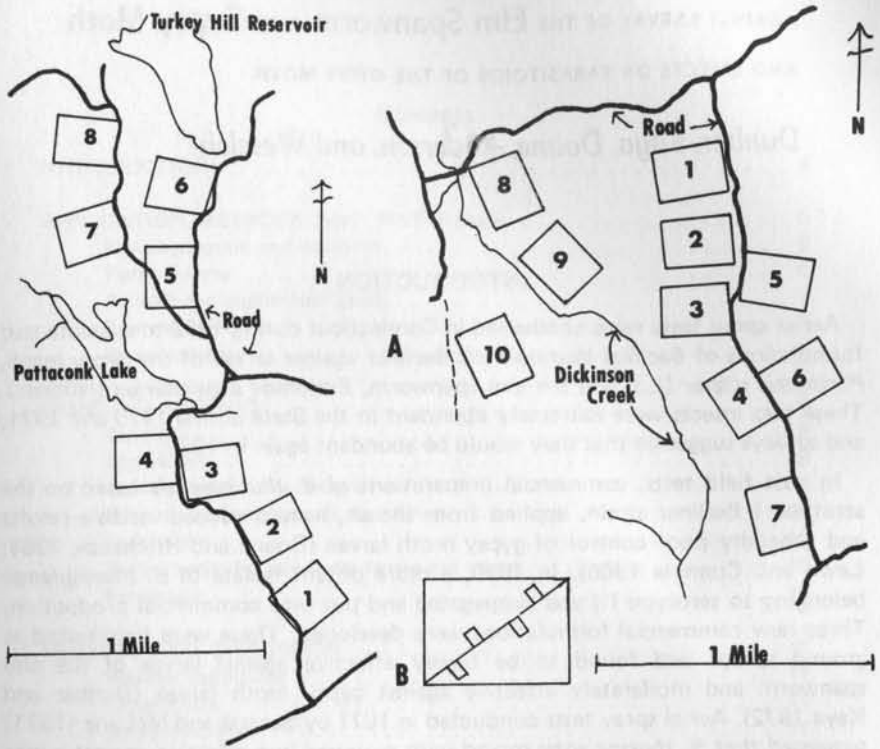

Fig. 1. Map of the test area in Cockaponset State Forest.

Fig. 2. (A) Map of the test area in Salmon River State Forest and (B) plot showing the layout of subplots.

northern red oak, and 50% red maple; hickory, *Carya* sp., and black birch. A more complete description of the vegetation in CSF is given by Stephens and Waggoner (1970). Their Turkey Hill tract is located adjacent to our Plot 8.

Corners of each plot were marked with plastic garbage bags pulled over the foliage of a cut sapling. A tree climber wired the sapling to the top of a large tree at each corner of the plot so that the bag was above the canopy. Plots receiving the same treatments were marked with bags of the same color. Edges of the plots were marked at ground level with plastic flagging.

Formulations

Formulations of *B. thuringiensis* tested were prepared by International Minerals Corporation, Libertyville, Illinois, and included Thuricide HPC® and an experimental preparation, IMC 90012. Both formulations contained 16 billion International Units (BIUs) per gal. These materials were applied with various additives to deliver 4 or 8 qt of finished spray mixture per acre.

Table 1.—Finished spray mixtures evaluated in Connecticut against larvae of gypsy moth and elm spanworm. June 1972.

Materials	Mixture (Qt/gal finished spray) A	B	C	D	E
IMC 90012	2.00	—	—	—	—
Thuricide HPC	—	1.00	2.00	1.00	2.00
CIB	—	1.00	1.00	—	—
Pinolene	—	.13	.13	—	—
Propionic acid	—	.01	.01	—	—
Rhoplex AC-33	—	—	—	.35	.17
Water	2.00	1.86	.86	2.65	1.83
Total	4.00	4.00	4.00	4.00	4.00

Finished spray mixtures are given in Table 1. The additives in mixtures B and C were Cargill Insecticide Base (CIB) (Cargill Co., Minneapolis, Minn.) which constituted 25% (v/v) of the finished spray, Pinolene (Miller Chemical and Fertilizer Corp., Hanover, Penn.) at 3.3% (v/v), propionic acid (Mallinckroft Chemical Works, St. Louis, Mo.) at 0.25% (v/v) and water. The additives in mixtures D and E were Rhoplex AC-33 (Rohm and Haas, Philadelphia, Penn.) and water. Rhoplex is a 46% acrylic resin, which was used as a sticker-spreader.

Aircraft and application dates

The aircraft used was a Pawnee fitted with a standard spray system. All spray mixtures, with the exception of IMC 90012, were prepared in a mixing tank equipped with a pump and an agitation system. IMC 90012 was mixed in the spray tank of the plane. After each material was transferred into the plane, agitation was continuously maintained. Nozzles used in the application of the materials were 12 D-6 hollow cones with 45° swirl plates directed down and slightly forward.

Plots were sprayed between June 2 and June 8 (Table 2) when the majority of elm spanworm larvae were in the 4th instar and the gypsy moth larvae were in the 3rd and 4th instars. The pilot flew along the long axis of the plots at an approximate altitude of 50 ft above the tree tops and moved laterally across the plots with swath widths of 75 ft. All plots were sprayed in this manner except Plots 4 and 5 in SRSF. Due to the increased gallonage applied to these plots, it was necessary to spray one time along the long axis and a second time along the short axis. In most instances one or two observers were stationed in each plot as it was being sprayed.

Spray droplet size

Spray droplet size was recorded for finished spray mixtures A, B, and C (Table 1) at the airport. The method was similar to that described by May (1950). Glass plates 3¼ inches by 4 inches were coated with magnesium oxide on one side by moving a burning magnesium ribbon back and forth 4 to 6 inches under the plate. Plates were then placed on the runway in a line directly beneath and at

Table 2.—Dates of application for the designated plots in Cockaponset and Salmon River State Forests.

Plot No.	Treatment: Spray mixture[1]	Formulation	Qt formulation/acre	Sticker	No. applications	Date of application
			Cockaponset			
1 5	C	HPC	2	CIB	1	6/2
3 6	B	HPC	1	CIB	1	6/4
4 8	D	HPC	1	Rhoplex	1	6/4
2 7		untreated	—	—	—	—
			Salmon River			
9 10	A	IMC 90012	2	None	1	6/8
7 8	C	HPC	2	CIB	2	6/4, 6/8
1 3	C	HPC	2	CIB	1	6/2 6/3
4	C	HPC	2	CIB	2	6/8[2]
5	E	HPC	2	Rhoplex	2	6/8[2]
2 6		untreated	—	—	—	—

[1] Letters correspond to Table 1.
[2] Two applications on the same morning.

right angles to the proposed flight of the plane. The plane loaded with a specific spray mixture then sprayed the area occupied by the plates from a height of approximately 50 ft. Five minutes after spraying, plates were removed from the field and taken to the laboratory. Eighty to 100 droplets found at random on each plate were measured with a dissecting microscope fitted with an ocular micrometer.

Spray coverage

Spray coverage of the Thuricide HPC-CIB mixture applied to Plot 4 in SRSF was analyzed by methods developed by Maksymiuk et al. (1971) and Yates and Akesson (1963). Two hundred twenty gm of Rhodamine B Extra Base Dye (GAF Corp., New York, N.Y.) were mixed with 60 gal of the finished spray. Within 3 hr after spraying, 6 red oaks, 7-11 inches dbh and 56-68 ft tall, were selected and felled. Leaf samples were taken at the top, middle and bottom of the crown from all four cardinal directions as well as along the axis. Leaf samples

were placed into plastic bags and transported to the laboratory for spray deposit analysis. Leaves were kept at 4°C until analyzed.

For each leaf sample, approximately 500 cm^2 of surface area were measured with a leaf-area machine (Hayashi Denko Corp., Tokyo, Japan). Spray deposits were removed by placing leaves in 100 ml of 30% aqueous ethanol solution for 20 min with continuous agitation. The ethanol solution was then filtered with Whatman No. 42 filter paper (W.R. Balston Ltd., England). The concentration of the fluorescent tracer was measured with a Perkin-Elmer Fluorescence Spectrophotometer 203 (Perkin-Elmer Corp., Norwalk, Ct.) with the excitor and analyzer wavelengths set at 365 and 575 nm, respectively. Unsprayed oak leaves were treated in a similar manner to obtain an indication of the background reading. The amount of fluorescent dye on the leaf samples was compared with a standard prepared from the finished spray collected just prior to spray application. For calculation of the amount of *B. thuringiensis* spray per cm^2 of leaf, the reading obtained for the highest value of the untreated leaves was subtracted from the treated leaves to obtain the true reading.

SAMPLING METHODS

Subplots

Data used in evaluating the effectiveness of the sprays were collected from 0.2-acre subplots in each plot. Four subplots were set out on a diagonal across each plot at 4-chain intervals (Fig. 2B). The subplot dimensions were 1 chain by 2 chains.

Egg masses

Before gypsy moth larvae had hatched in the spring, pretreatment estimates of the population density were made by counting the number of egg masses in each subplot. These counts were made by two observers who each counted the visible egg masses in one-half of the subplot. Their counts were then combined to give a total number of egg masses per subplot. No attempt was made to climb trees or overturn material on the ground in search of egg masses. In early November, a posttreatment count was made by the same observers who made the initial count.

Pretreatment counts of elm spanworm egg masses were taken in all plots and indicated that the infestation in both CSF and SRSF would be heavy. Posttreatment counts of elm spanworm egg masses were not taken.

Sizes of gypsy moth egg masses were determined by using a template and categorized as follows: Small with less than 200 eggs; medium-small with 201-400 eggs per mass; medium-large with 401-600 eggs per mass and large with 601 or more eggs per mass (Doane, manuscript in preparation).

Terminal counts for living larvae

An estimation of the density of larvae of gypsy moth and elm spanworm was made in each subplot before and after treatment by counting the number of larvae per foot of terminal on 10 terminals in each of the following tree groups: White oak, red oak, and maple. Pretreatment counts were made at SRSF on May

25 and 26 with the exception that Plot 10 was counted on May 30. Counts in the plots at CSF were made on May 23 and 24. Posttreatment counts were made in all plots approximately 8 to 10 days after treatment.

Drop cloths for frass and dead larvae

Two 1 yd^2 drop cloths were placed in each subplot under dominant host trees, usually oaks. All cloths were cleared of frass and larvae just before treatment and were then checked for dead larvae periodically thereafter. Usually, dead larvae on the cloths were counted every 1 or 2 days. Frass was usually removed from each cloth at weekly intervals. In the laboratory, frass was separated from large leaf fragments and insect parts, oven-dried and weighed to the nearest tenth of a gm on a Mettler balance.

Defoliation

Prior to treatment in late May, 80 dominant and co-dominant trees of all species were selected at random and identified to species in each plot (20/subplot). Two observers, working independently, scored the defoliation of each tree on a scale from 1 to 6 which corresponds to the following defoliation categories: 1-10%, 11-25%, 26-50%, 51-75%, 76-99% and 100%, respectively. At the cessation of larval feeding the same observers again estimated defoliation. For purposes of analysis the defoliation estimates of the two observers were averaged and the median values of the defoliation categories used in the calculation.

Burlap bands for late-instar larvae and pupae

Burlap bands, 12 inches wide, were used to assess numbers of surviving gypsy moth larvae and pupae in test plots in SRSF. The burlap was placed at breast height around 10 dominant oak trees per subplot between June 12-16. At that time, the majority of the gypsy moth larvae were in the 4th instar. Counts of larvae and pupae that had congregated under the burlap bands were made between July 10 and 12. Burlap bands were not placed on trees in CSF.

Parasitoids

An evaluation of the effects of the *B. thuringiensis* sprays on some natural enemies of the gypsy moth was conducted in SRSF. The data were collected from one randomly selected subplot in each plot. In one study, the number of overwintering cocoons of the braconid *Apanteles melanoscelus* (Ratzeburg) was estimated by counting the number of cocoons under each of the 10 burlap bands per subplot.

In a second study, periodic collections of gypsy moth larvae and pupae were made at each selected subplot. Larvae were collected for ½ hr at each subplot or until 50 individuals had been collected, whichever came first. They were reared individually on artificial diet (Leonard and Doane 1966) in plastic 6 cm diam petri dishes at 22±3°C, 50% RH, and 16 hr photophase and were retained after pupation in 1 oz plastic cream cups until parasitoid emergence, adult emergence, or death occurred.

RESULTS AND DISCUSSION

Weather conditions

June was excessively wet and cool in Connecticut. Record low temperatures and high precipitation occurred, and fog and flooding were common in many places. Daily temperature and precipitation readings taken at the nearby Middletown, Ct. weather station are summarized for the period between June 1 and 15 in Fig. 3. There was minimal rainfall on the spray dates of June 2, 3, 4, and 8. Two light rains occurred on June 5 and 7 and one heavy rain occurred on June 10.

Conditions at the time of spraying were generally favorable with one exception. On June 3, when Plot 3 in SRSF was sprayed, the woods were very wet and leaves were covered with fine water droplets which prevented proper deposit of spray. Wind speed and relative humidity were measured in SRSF during each of the spraying operations. Wind speeds never exceeded an average of 2 mph (measured at 12 ft height) and RH was 90%, 78%, 85% and 85% on June 2, 3, 4, and 8, respectively.

Droplet size

The spray droplet size of three finished spray mixtures varied and ranged from 33μ to 1122μ (Table 3). Droplets collected directly beneath the plane were often smaller than the other droplets.

Spray mixtures

The Thuricide HPC-CIB mixture and the IMC 90012 mixture were applied without difficulty, but certainly IMC 90012 was the easiest to prepare since only water had to be added.

The acrylic resin, Rhoplex AC-33, was intended to be applied to four plots. During application of a 4% suspension mixed with Thuricide HPC to Plots 4 and 8 in CSF, the emulsion broke and the spray nozzles clogged. It was necessary to increase the spray pressure in order to complete the application of spray. Tests conducted in the laboratory showed that the emulsion would not break down under agitation. Therefore, it is possible that contaminants in the mixing tank or in the spray tank of the plane caused the emulsion to break.

An attempt was made to clean the mixing tank and the spray system of the plane throughly before applying a 2% suspension of Rhoplex mixed with Thuricide HPC (spray mixture E, Table 1) to Plots 4 and 5 in SRSF. Enough finished spray was mixed to treat Plot 5. Again the emulsion broke during the spray operation and it was necessary to increase the spray pressure to discharge the spray. The use of Rhoplex was discontinued and Plot 4 was treated with the Thuricide HPC-CIB mixture at the rate of 4 qt Thuricide HPC per acre.

Data collected from Plots 4 and 5 were compared. No significant differences occurred in the results and the plots were combined as replicates.

Table 3.—Droplet size (μ) of three finished spray mixtures recorded on magnesium oxide coated glass plates placed directly beneath and at various distances to the left and to the right of the path of the plane. Chester, Conn. June 1972.

	30 ft to left		18 ft to left		Directly beneath		18 ft to right		30 ft to right	
Spray mixture	$\bar{X}$	range	$\bar{X}$	range	$\bar{X}$	range	$\bar{X}$	range	$\bar{X}$	range
C[1]	269	33-561	275	33-660	209	33-660	238	33-726	283	33-759
A	—	—	—	—	183	33-726	348	99-924	385	99-1155
B	—	—	398	132-858	279	99-990	338	99-990	511	132-1122

[1] Letters correspond to Table 1

Table 4.—Calculated international units (IUs) per cm^2 of leaf area from Plot 4 in Salmon River State Forest sprayed with Thuricide HPC at a rate of 16 BIUs per acre.

Location in the canopy	No. trees	No. samples per tree	$\bar{X}$ IUs per cm^2
Top	6	5	42.7
Middle	6	5	29.4
Bottom	6	5	29.7

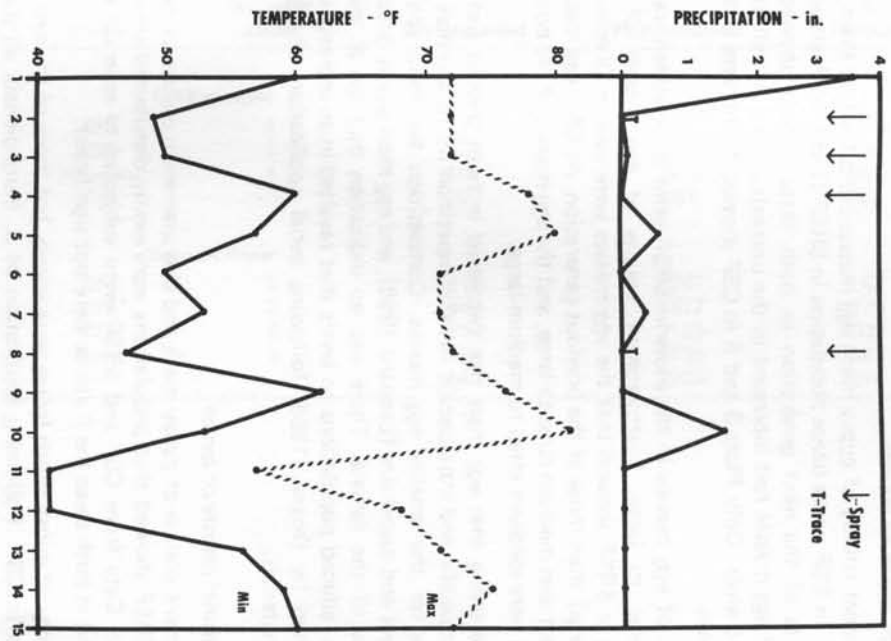

Fig. 3. Daily temperature and precipitation records for June 1-15, 1972 at Middletown, Conn.

Spray distribution in the canopy

The fluorescent tracer, Rhodamine B Extra Base, provided a simple means to assess spray coverage immediately after spraying. Quantitative assessment of the spray coverage was made by expressing the spray deposit in international units (IUs) of *B. thuringiensis* per cm^2 of leaf area (Table 4). More spray was deposited in the tops of the canopies than lower down, but the results were not significantly different. These data were unexpected since other workers have shown that significantly more spray is deposited in the tops of plants than lower down (Joyce et al. 1969). Our results may be due to the double application of spray applied to Plot 4.

Gypsy moth egg mass counts

Pretreatment counts of gypsy moth egg masses indicated that there was a light population in CSF and a dense population in SRSF (Table 5). Posttreatment egg mass counts of the next generation in both State Forests showed that the number of egg masses had increased in the untreated plots as well as in all but two treated plots. Only Plots 3 and 6 in CSF showed no increase in the number of egg masses.

The size of egg masses in the plots in SRSF prior to treatment ranged from medium-large to large. Posttreatment counts of egg masses of the next generation in SRSF showed that the egg masses were smaller (medium-small to medium-large) than those of the previous generation. At CSF, egg mass size prior to treatment was medium-large to large, and the egg masses of the posttreatment generation were medium-small to medium-large.

It is interesting that egg mass size decreased in both treated and untreated plots. Interspecific and intraspecific larval competition for foliage may have been responsible for the smaller egg masses. Competition for food and crowding reduce larval and pupal size (Leonard 1968), and egg mass size is directly related to the size of the female. There was no indication that the *B. thuringiensis* treatments reduced populations to levels that resulted in an increase in egg mass size as noted by Doane (1968) following aerial application of experimental chemical materials.

Branch terminal counts of larvae

Pretreatment counts of gypsy moth and elm spanworm on branch terminals in CSF and SRSF showed that populations were evenly distributed among plots in each forest. Data from CSF and SRSF were subjected to separate analyses of variance and in both cases the F values were not significant.

Populations of gypsy moth larvae were sparse, but those of the elm spanworm were dense in CSF. Following application of *B. thuringiensis,* all treated plots had significantly fewer elm spanworm larvae on terminals than untreated plots, but there were no differences between treated plots (Table 6). Numbers of gypsy moth larvae following treatment in treated plots were not significantly different from numbers in untreated plots in CSF. However, significantly fewer gypsy moth and elm spanworm larvae were found in all treated plots compared with the untreated plots following application of *B. thuringiensis* in SRSF (Table 6). There were no significant differences in larval numbers between the treated plots.

Drop cloth samples of larvae

The mean number of dead and paralyzed larvae falling from the trees into drop cloths is shown in Table 7. The data were transformed for purposes of statistical analysis using the square root transformation. In both State Forests, a significantly higher number of gypsy moth and elm spanworm larvae were collected in the treated plots than in the untreated plots, but few differences were noted between treated plots.

Table 5.–Mean number of gypsy moth egg masses/acre in Cockaponset and Salmon River State Forests before and after application of *B. thuringiensis.*

Plot Nos.	Treatment				$\bar{X}$ No. egg masses/acre		
	Formulation	Qt formulation/acre	Sticker	No. applications	Pretreatment	Posttreatment	% increase
Cockaponset							
3 & 6	HPC	1	CIB	1	170	150	None
1 & 5	HPC	2	CIB	1	223	368	165
4 & 8	HPC	1	Rhoplex	1	100	302	301
2 & 7	untreated	—	—	—	227	591	260
Salmon River							
7 & 8	HPC	2	CIB	2	816	1201	147
4 & 5	HPC	2	CIB[1]	2	584	1317	226
1 & 3	HPC	2	CIB	1	714	2133	302
9 & 10	IMC 90012	2	None	1	257	1730	673
2 & 6	untreated	—	—	—	563	2915	518

[1]Plot 5 received Rhoplex.

Table 6.—Mean number of gypsy moth and elm spanworm larvae per 10 branch terminals after application of *B. thuringiensis* in Cockaponset and Salmon River State Forests.

Plot Nos.	Treatment				Gypsy moth[1]		Elm spanworm[2]	
	Formulation	Qt formulation/acre	Sticker	No. applications	Pretreatment	Posttreatment[3]	Pretreatment	Posttreatment[3]
				Cockaponset				
1 & 5	HPC	2	CIB	1	4.4	1.1	33.6	2.9a
4 & 8	HPC	1	Rhoplex	1	6.1	1.2	51.2	6.2a
3 & 6	HPC	1	CIB	1	2.0	5.1	37.4	12.6a
2 & 7	untreated	——	——	——	6.3	5.0	60.9	55.9 b
				Salmon River				
7 & 8	HPC	2	CIB	2	24.9	6.3a	16.7	2.4a
9 & 10	IMC 90012	2	None	1	22.5	5.4a	53.4	4.7a
4 & 5	HPC	2	CIB[4]	2	17.1	5.9a	27.5	4.8a
1 & 3	HPC	2	CIB	1	17.9	5.6a	28.2	8.3a
2 & 6	untreated	——	——	——	22.2	18.5 b	25.3	27.9 b

[1]Mean number of gypsy moth larvae on oaks.
[2]Mean number of elm spanworms on oaks and maples.
[3]Duncan's test at 5% level.
[4]Plot 5 received Rhoplex.

Table 7.—Mean number of dead gypsy moth and elm spanworm larvae collected per drop cloth per day during the initial 11 days following application of *B. thuringiensis* in Cockaponset State Forest and during the initial 8 days following application in Salmon River State Forest.

Plot Nos.	Treatment				$\bar{X}$ No. dead larvae/cloth/day	
	Formulation	Qt formulation/acre	Sticker	No. applications	Gypsy moth	Elm spanworm
			Cockaponset			
1 & 5	HPC	2	CIB	1	7.5a[1]	79.1a[1]
3 & 6	HPC	1	CIB	1	3.1 b	99.9a
4 & 8	HPC	1	Rhoplex	1	3.7 b	83.6a
2 & 7	untreated	——	——	——	0.7 c	5.1 b
			Salmon River			
7 & 8	HPC	2	CIB	2	12.9ab	65.1a
9 & 10	IMC 90012	2	None	1	17.5a	62.9a
4 & 5	HPC	2	CIB[2]	2	6.2 c	60.6a
1 & 3	HPC	2	CIB	1	10.6bc	37.7a
2 & 6	untreated	——	——	——	2.6 d	3.4 b

[1]Duncan's test at 5% level.
[2]Plot 5 received Rhoplex.

Within a few hours after treatment, large numbers of elm spanworm larvae were observed dropping from the trees, whereas few gypsy moth larvae were observed dying even after 3 to 5 days. The largest number of elm spanworm larvae was collected within 24 hours after treatment, though large numbers continued to be collected for about a week after treatment. These results are similar to those reported by Dunbar and Kaya (1972) for elm spanworm and by Quinton and Doane (1962), Doane and Hitchcock (1964) and Lewis and Connola (1966) for other geometrids. The largest number of gypsy moth larvae was collected on drop cloths 3 to 4 days following treatment. Doane and Hitchcock (1964) reported that mortality was highest 5 days after treatment with Thuricide 90T.

Few gypsy moth larvae were collected on drop cloths, including those placed in SRSF where the pretreatment population was high. Terminal counts for gypsy moth larvae (Table 6) showed that there was significant reduction in numbers after treatment in all plots in SRSF, but decreases in living larvae were not evident by the small numbers of larvae collected on the cloths. Larvae infected with *B. thuringiensis* die slowly (Doane and Hitchcock 1964) and those that fell onto the cloths may have been able to crawl off them before dying. The infected larvae may have also left the foliage and crawled back to sheltered places on the bole where they ultimately died. Whatever the explanation, it appears that drop cloths do not give realistic assessments of gypsy moth mortality from *B. thuringiensis*. Lewis and Connola (1966) also concluded that drop cloths proved to be inconclusive in evaluating gypsy moth mortality after treatment with *B. thuringiensis*.

Drop cloth samples of frass

Frass collected from drop cloths was not separated to species; therefore, weights of frass are a composite. The average dry weight of frass per cloth and dates of collections for both CSF and SRSF are given in Table 8. A statistical analysis of the frass data was not performed because of missing data. Several of the cloths were flooded and a few others were torn apart by birds and racoons.

The first collection after treatment in each forest shows that foliage consumption, as indicated by frass weight, was reduced considerably in all treated plots, in comparison to untreated plots, but there were no noticeable differences between treated plots. Undoubtedly, most of the differences observed in frass production between treated and untreated plots were caused by a reduction of elm spanworms. Later collections showed that a number of larvae, mainly gypsy moth, continued to feed throughout June and the first half of July until completion of development.

Burlap bands

Significantly fewer gypsy moth larvae and pupae were found under burlap bands in plots treated with three of the sprays (Table 9). However, large numbers of gypsy moth larvae survived in all plots indicating that the treatments were not highly effective for this species.

Table 8.–Average weight (gm) of frass collected per drop cloth from various species of caterpillars feeding in treated and untreated woodland in Cockaponset and Salmon River State Forest.

Plot Nos.	Treatment: Formulation	Qt formulation/acre	Sticker	No. applications	Dates collected: 6/16	6/26	7/6
			Cockaponset				
1 & 5	HPC	2	CIB	1	3.6	5.1	7.5
3 & 6	HPC	1	CIB	1	6.8	3.3	2.2
4 & 8	HPC	1	Rhoplex	1	6.0	5.8	5.4
2 & 7	untreated	—	—	—	22.9	10.6	7.4
			Salmon River		6/15	6/28	7/7
9 & 10	IMC 90012	2	None	1	4.4	11.7	5.5
1 & 3	HPC	2	CIB	1	4.7	12.9	8.4
7 & 8	HPC	2	CIB	2	5.8	15.2	11.3
4 & 5	HPC	2	CIB[1]	2	6.5	10.0	5.6
2 & 6	untreated	—	—	—	13.5	30.0	10.7

[1]Plot 5 received Rhoplex.

It is interesting to note that when these counts were made there was a higher percentage of gypsy moth pupae under burlap bands in treated plots than in untreated plots. These data suggest that *B. thuringiensis* may have affected larval feeding directly by prolonging larval development. It is also possible that temperatures increased in heavily defoliated untreated plots resulting in more rapid growth of larvae. There also may have been a limited number of niches available for the large numbers of larvae in the defoliated plots, resulting in large numbers of prepupae congregating under burlap.

Defoliation

Defoliation data are expressed as percent defoliation per tree (Table 10). For purposes of statistical analysis, the raw data were transformed to the arcsin transformation. Not all tree species were defoliated to the same degree; consequently data are presented for all species grouped together and for oaks separately. Final defoliation represents the average maximum defoliation per tree. Net defoliation represents the difference between final and pretreatment defoliation.

In CSF, significantly greater foliage protection was achieved in treated trees compared to untreated trees. When all tree species were grouped, Thuricide-CIB at 2 qt per acre provided significantly greater foliage protection than at 1 qt per acre. This difference was not apparent when oaks were compared separately. No differences in defoliation were observed between plots sprayed with Thuricide-CIB or with Thuricide-Rhoplex mixtures.

In SRSF, the data showed that final defoliation was 50% or less in all treated plots—a significant level compared to the untreated plots. There were no significant differences between treatment means in net defoliation for all species. The net defoliation for oaks revealed that two applications of Thuricide at 2 qt per acre applied on the same day provided significantly greater foliage protection than one application of 2 qt per acre.

EFFECTS ON GYPSY MOTH PARASITOIDS

Analysis of variance of numbers of *A. melanoscelus* cocoons under burlap indicated that no significant differences occurred between untreated and treated plots. Therefore, there is no indication that the spray treatments influenced the numbers of overwintering *A. melanoscelus* cocoons.

Parasitoids reared from gypsy moth larvae and pupae included: *A. melanoscelus;* the ichneumon, *Phobocampe disparis* (Viereck); the chalcid, *Brachymeria intermedia* (Nees); and the tachinids, *Compsilura concinnata* (Meigen), *Blepheripa scutellata* (Robineau-Desvoidy), and *Parasitigena agilis* (Robineau-Desvoidy). Of these, only *A. melanoscelus, B. scutellata,* and *P. agilis* were sufficiently abundant for further consideration.

Results are presented in Table 11. Statistical analysis (contingency table chi-square) showed that the average percent parasitism by *A. melanoscelus* was significantly less in the untreated plots than in the treated plots. This may be a

Table 9.–Mean number of gypsy moth larvae and pupae under burlap per tree, July 10-12, Salmon River State Forest.

Treatment					$\bar{X}$ No. larvae and pupae/tree	% pupae
Plot Nos.	Formulation	Qt formulation/acre	Sticker	No. applications		
9 & 10	IMC 90012	2	None	1	20.7a[1]	21.3
4 & 5	HPC	2	CIB[2]	2	23.3a	14.7
7 & 8	HPC	2	CIB	2	23.6a	18.3
1 & 3	HPC	2	CIB	1	59.1 b	38.8
2 & 6	untreated	—	—	—	76.9 b	55.5

[1]Duncan's test 5% level.
[2]Plot 5 received Rhoplex.

Table 10.–Percent defoliation observed per tree after cessation of larval feeding in Cockaponset and Salmon River State Forests.

Treatment					$\bar{X}$ Defoliation/tree			
					All species		Oaks	
Plot Nos.	Formulation	Qt formulation/acre	Sticker	No. applications	Final	Net	Final	Net
Cockaponset								
1 & 5	HPC	2	CIB	1	28.2	12.4a[1]	31.7	14.1a[1]
3 & 6	HPC	1	CIB	1	40.0	18.1 b	57.3	23.3a
4 & 8	HPC	1	Rhoplex	1	39.9	18.8 b	46.2	20.6a
2 & 7	untreated	—	—	—	64.6	43.7 c	79.1	52.3 b
Salmon River								
7 & 8	HPC	2	CIB	2	36.8	23.3a	49.0	32.4ab
4 & 5	HPC	2	CIB[2]	2	39.2	24.4a	42.1	26.8a
9 & 10	IMC 90012	2	None	1	39.9	26.5a	49.9	36.3ab
1 & 3	HPC	2	CIB	1	43.7	33.1a	50.5	39.4 b
2 & 6	untreated	—	—	—	63.5	52.7 b	70.3	51.7 c

[1]Duncan's test at 5% level.
[2]Plot 5 received Rhoplex.

Table 11.—Average percent parasitism by three abundant parasitoids of gypsy moth after application of *B. thuringiensis* in Salmon River State Forest.

Parasitoids	Collection date	Untreated plots	Treated plots
A. melanoscelus	6/27	1.0	13.3
B. scutellata	7/12-17	15.4	15.0
P. agilis	6/29 + 7/12-17	1.1	3.4

result of too few gypsy moth larvae being available for parasitism by *A. melanoscelus* in the treated plots. The adult populations of *A. melanoscelus* were probably quite uniform in both the untreated and treated plots because of dispersion. Consequently, a greater proportion of parasitoids in relation to hosts would occur in the treated plots, thus resulting in the higher percent parasitism observed there.

No substantial differences occurred for percent parasitism with the other parasitoids. These data indicate that the *B. thuringiensis* sprays did not influence these three species of gypsy moth parasitoids.

SUMMARY

Tests conducted in Cockaponset State Forest (CSF) and Salmon River State Forest (SRSF) showed that elm spanworm larvae were controlled effectively with one application of Thuricide HPC at rates as low as 1 qt per acre. One application of IMC 90012 at 2 qt per acre was also effective.

In CSF, where elm spanworm predominated and gypsy moth was at a low level, foliage protection was achieved. Net defoliation was less than 25% on treated oaks compared to 52.3% on untreated oaks and less than 20% on all treated trees compared to 43.7% on all untreated trees.

Some foliage protection was achieved in treated plots in SRSF compared to untreated ones. Net defoliation was held below 40% on treated oaks compared to 51.7% on untreated oaks and below 33% on all treated trees compared to 52.7% on all untreated trees.

Numbers of gypsy moth larvae were reduced by all but one treatment in CSF, and significantly reduced by all treatments in SRSF. Nevertheless, sufficient numbers remained in both State Forests to cause postreatment egg mass counts to increase over pretreatment counts in all but two plots. The elm spanworm served as a good marker insect because control was achieved in all treated plots, indicating that spray coverage was satisfactory.

Bacillus thuringiensis had no apparent effects on the three gypsy moth parasitoids, *A. melanoscelus, B. scutellata*, and *P. agilis.*

IMC 90012 appears to be comparable to Thuricide HPC in its performance against gypsy moth and elm spanworm, and it is certainly much easier to work with when preparing the finished spray mixture.

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