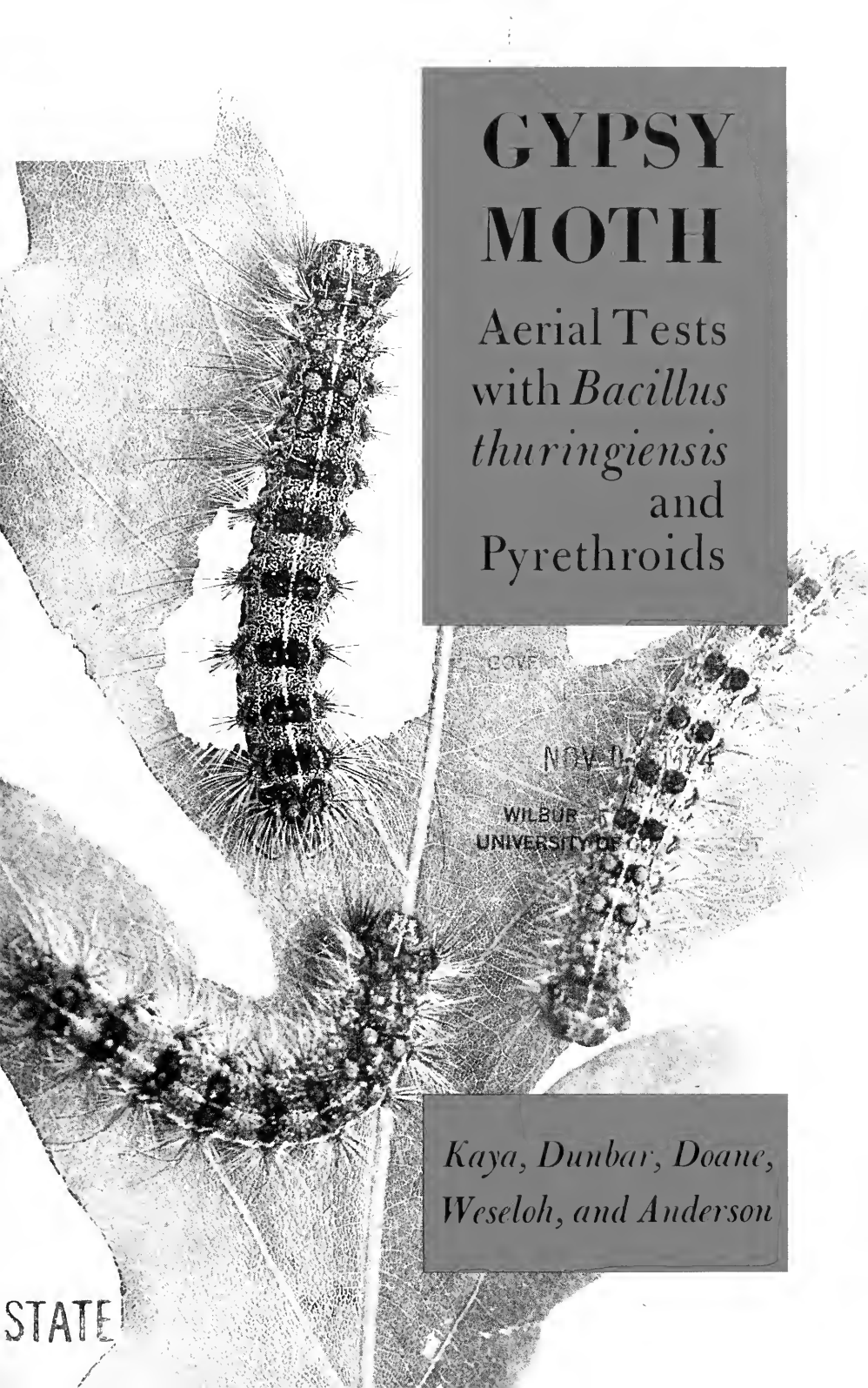
GYPSY MOTH

Aerial Tests with *Bacillus thuringiensis* and Pyrethroids



Kaya, Dunbar, Doane, Weseloh, and Anderson

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Abstract

Two formulations of *Bacillus thuringiensis* Berliner, Dipel® and Thuricide®-16B, and two synthetic pyrethroids, resmethrin (SBP-1382) and bioethanomethrin (RU 11679) were aerially tested against the gypsy moth, *Porthetria dispar* (L.), in Connecticut. Dipel applied at the rate of 1 lb/acre or 7.26 Billion International Units (BIU)/acre and Thuricide-16B applied at the rate of 2 qt/acre or 8 BIU/acre provided some foliage protection.

Pyrethroids applied at the rate of 0.05 lb active ingredient/gal/acre did not provide foliage protection. The knock down rate was high, but many larvae recovered, ascended the trees, and continued to feed.

There was a significant reduction in the number of egg masses per acre in the *B. thuringiensis* plots as compared to the untreated plots. The number of egg masses in plots treated with pyrethroids was not different from the untreated plots. There was a marked reduction in the posttreatment egg mass counts as compared with the pretreatment counts in all plots. In the *B. thuringiensis* plots the number of eggs per mass was significantly higher than in the untreated plots, but there was no significant difference in the number of eggs per mass between the pyrethroid or untreated plots.

There were significant differences of spray deposits of Thuricide-16B between the D-2 hollow cone nozzles and the D-4 and D-6 nozzles but not between the D-4 and D-6 nozzles. These differences are believed to be the result of the manner in which the sprays were applied.

The pyrethroids apparently killed many larvae and adults of nontarget insects, while *B. thuringiensis* primarily affected larval Lepidoptera and adult Coleoptera.

Acknowledgments

We thank Misses D. Brown and B. Tracanna and Messrs. W. Gray, G. Hubeny, R. Moore, G. Piontek, K. Welch, and H. Williams for their technical assistance.

We especially thank the pilot, Mr. T. Ziemba, for his full cooperation in applying the sprays and Mr. F. Jewett for allowing us to use his land as one of the untreated plots.

GYPSY MOTH: AERIAL TESTS

with *Bacillus thuringiensis* and Pyrethroids

Harry Kaya, Dennis Dunbar, Charles Doane, Ronald Weseloh, and John Anderson

Introduction

Encouraging results with ground application of synthetic pyrethroids (Dunbar and Doane 1973) and aerial application of *Bacillus thuringiensis* Berliner in 1972 (Dunbar *et al.* 1973) against larvae of the gypsy moth, *Porthetria dispar* (L.), led to further studies in 1973. Synthetic pyrethroids are broad spectrum insecticides, but their use is advantageous because of their rapid degradation in the environment and their low mammalian toxicity.

On the other hand, *B. thuringiensis (Bt)* is a selective microbial insecticide which is effective against many lepidopterous

insects. Aerial tests against the gypsy moth have produced variable results. Doane and Hitchcock (1964) reported that *Bt* was not effective from the air, while Lewis and Connola (1966) showed that *Bt* reduced the population to nearly acceptable levels. Dipel mixed with molasses was found effective by Secrest and McLane (1971) against the gypsy moth and Dunbar *et al.* (1973) showed that Thuricide-16B (formerly IMC 90012) compared favorably with Thuricide HPC. We conducted aerial tests with two pyrethroids, resmethrin and bioethanomethrin, and two *Bt* materials, Dipel and Thuricide-16B, against the gypsy moth and evaluated the impact of *Bt* and pyrethroid sprays on some nontarget insects. We also studied the distribution of spray deposits in the canopy from using different nozzle sizes.

Application Materials and Methods

Plot description and markings

Ten test plots, 30 acres in size (14 × 21 chains, 1 chain = 66 ft), were established in Nehantic State Forest in Old Lyme, Ct. (Fig. 1A). This forest is a mixed hardwood stand dominated by oaks 40 to 70 ft tall. The terrain ranged from 140 to 450 ft above sea level. Four subplots, 0.2 acre in size, were established along a diagonal across each plot (Fig. 1B) to evaluate the effectiveness of the treatments. Each plot was marked just prior to spraying by helium-filled weather balloons.

Formulations

Pyrethroids tested were resmethrin (SBP-1382) (S. B. Penick Co., New York, N.Y.) and bioethanomethrin (RU 11679) (MGK Corp., Minneapolis, Mn.). Both were formulated in mineral oil (Klearol, Witco Chem. Corp., Chicago, Il.) at the rate of 0.05 lb active ingredient/gal and were applied without further dilution at 1 gal/acre. Plots 1 and 3 were sprayed with resmethrin while Plots 2 and 8 were sprayed with bioethanomethrin.

Formulations of *Bt* tested were Thuricide ®-16B (formerly IMC 90012) (Sandoz-Wander Inc., Homestead, Fl.) and Dipel® (Abbott Laboratories, North Chicago, Il.). Thuricide-16B was applied at the rate of 2 qt of aqueous concentrate or 8 Billion International Units (BIU)/acre. An equal volume of water was added to the aqueous concentrate and 1 gal of the finished spray material was applied per acre to Plots 5 and 7 (Fig. 1A). Dipel was applied at the rate of 1 lb or 7.26 BIU with 1 qt of Cargill Insecticide Base (molasses) (Cargill Co., Minneapolis, Mn.), 4 oz of Nu-Film-17® (Miller Chemical and Fertilizer Corp.,

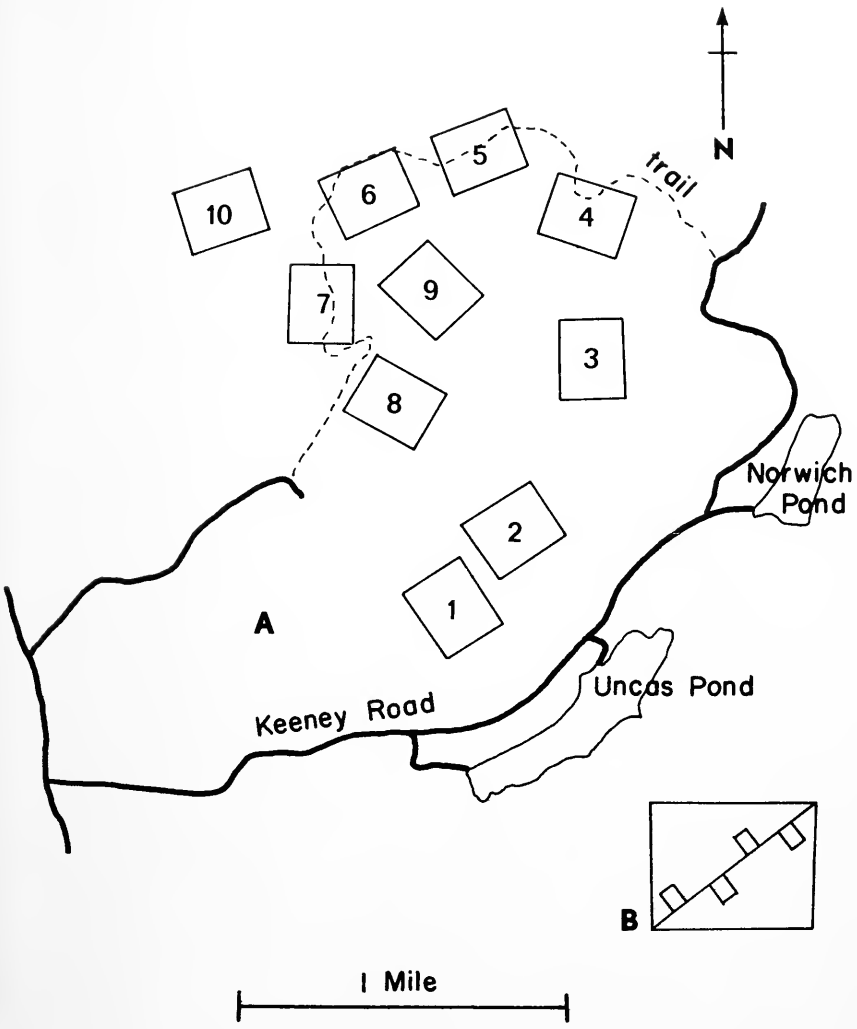


Fig. 1 (A) Map of the test area in Nehantic State Forest and (B) plot showing the layout of subplots.

Hanover, Pa.) and sufficient water added to make 1 gal of finished spray mixture. One gal/acre of the Dipel mixture was applied to Plots 4 and 6. Plots 9 and 10 served as untreated checks.

To study distribution of spray deposits in the canopy, 3.78 gm of Rhodamine B extra Base Dye (GAF Corp., New York, N.Y.) were added to each gal of Thuricide-16B finished spray mixture (0.1% w/v). The Thuricide-16B-dye mixture was applied at the rate of 8 BIU/acre or 1 gal/acre to plots in Salmon River State Forest in Marlborough, Ct.

Aircraft and application dates

The aircraft used was a Piper Pawnee fitted with a standard spray system containing 12 nozzles. The pyrethroids were added directly to the spray tank of the plane. Thuricide-16B was mixed in the spray tank while the Dipel mixture was prepared before being transferred to the plane. The spray mixes were agitated continuously until they were applied. D-2 and D-4 hollow cone nozzles were used to apply the pyrethroid and *Bt* materials respectively. The nozzles were fitted with 45° swirl plates directed downward and slightly forward.

Bt plots were sprayed on June 1 when most of the larvae were in their 2nd or 3rd instar. Pyrethroid plots were sprayed on June 8 when most of the larvae were in their 3rd or 4th instar. The Thuricide-16B-dye mixture was sprayed on June 14. All sprays were applied in the early morning to minimize the effects of wind and convection currents on the spray droplets.

The pilot sprayed a swath 75 ft wide along the long axis of the plots about 50 ft above the canopy. Three white cards (4 × 6 in) were placed in each subplot to determine the degree of coverage throughout the plot. In addition, 1 or 2 observers were usually stationed in each plot as it was being sprayed.

Spray droplet size

Spray droplet size was recorded for all materials. The method was similar to that described by May (1950) and Dunbar *et al.* (1973). Spray droplet size was recorded also for the spray coverage experiment conducted with Thuricide-16B-dye mixture sprayed with 3 different size nozzles (see below).

Spray distrubution in the canopy

Spray coverage of the Thuricide-16B-dye mixture was analyzed by methods developed by Yates and Akesson (1963), Maksymiuk *et al.* (1971), and Dunbar *et al.* (1973). Three linear

plots, 75 x 200 ft and 800 ft apart, were established in Salmon River State Forest. Thuricide-16B-dye mixture was applied with one pass made between 2 points over the long midline of each plot using D-2, D-4, or D-6 hollow cone nozzles. Within a few hours after spray application, 6 red oak trees, *Quercus rubra* L., 6-10 in dbh and 37-62 ft tall, were felled. Leaf samples were taken from the top, middle, and bottom of the crown, all 4 cardinal directions, and the axis. These samples were placed in plastic bags and stored at 4°C in the dark until spray deposition analyses were made. An hour before spray application, 3 red oak trees were cut and leaf samples taken from the various crown levels and directions to serve as untreated checks. Laboratory analysis was made as described by Dunbar *et al.* (1973).

Sampling Methods

Egg mass counts

Before gypsy moth larvae hatched in the spring, pretreatment estimates of the population density were made by counting egg masses in each subplot. However, trees were not climbed nor were materials on the ground overturned in search of egg masses. A posttreatment count was made in early December.

In October, 1973, 15 egg masses were collected from areas around the 40 subplots. These were placed individually in 1 oz cream cups. The egg masses were dehaired and the number of eggs in each mass was estimated by using a glass tube calibrated to count eggs in batches of one hundred (Doane ms. in prep.).

Drop cloth

Three 1 yd^2 drop cloths were placed under dominant oak trees in each subplot. All cloths were cleared of larvae just before treatment and checked for larvae periodically. The cloths were cleared after each count. In plots treated with pyrethroids, the number of gypsy moth larvae knocked down on the cloths was recorded 5 and 30 hours after treatment. In plots treated with *Bt*, cloths were examined for dead larvae every 1 or 2 days for the first 10 days following treatment. All nontarget insects found on the drop cloths were collected and identified to order. Natural enemies of the gypsy moth were identified to species.

Frass was collected from the drop cloths over a 3-day period (June 22-25) in all 10 plots. In the laboratory, frass was separated from large leaf fragments and insect parts, oven-dried, and weighed to the nearest 10th of a gram.

Branch terminal counts of living larvae

The number of living larvae on ten 2 ft terminals of oak were counted at reachable levels from the ground in each subplot. Pretreatment counts were made on May 22 in the *Bt* plots and on June 4 in the pyrethroid plots. Posttreatment counts were made in the *Bt* plots on June 7 and 12 and on June 12 in the pyrethroid plots. Counts were made in the untreated plots on the same dates as in the treated plots.

Burlap bands

Burlap bands, 12 inches wide, were used to assess numbers of surviving gypsy moth larvae and pupae. The burlap was placed at breast height around 10 dominant and co-dominant oak trees per subplot. Counts of live larvae and pupae found under the burlap bands were made on June 28 and 29. The number of cocoons of *Apanteles melanoscelus* (Ratzeburg) and larvae of *Calosoma sycophanta* (L.) under the bands were also counted. Counts of larvae of *C. sycophanta* were made in late June and cocoons of *A. melanoscelus* were made in late August and early September.

Defoliation

Two to four days before treatment, 40 dominant and co-dominant oak trees were selected in each plot for defoliation estimates (10/subplot). The defoliation of each selected tree was recorded by an observer on a scale from 1 to 6 as described by Dunbar *et al.* (1973). Pretreatment defoliation estimates were made on May 29 and 30 in the *Bt* plots and on June 5 and 8 in the pyrethroid plots. Pretreatment defoliation estimates for the untreated plots were made at the same time. Posttreatment defoliation estimates were made by the same observer on July 2 and 3 after cessation of larval feeding.

Parasitization of larvae and pupae

The incidence of parasitism was determined by collecting up to 100 gypsy moth larvae from each plot on June 12, and up to 100 larvae and pupae between June 26 and 28. Larvae were reared individually in 1 oz cream cups containing artificial diet (Leonard and Doane 1966). Pupae were also placed individually in cups. Each specimen was retained for 3 weeks and checked weekly for parasitoid emergence.

Results

Weather conditions

Conditions at the time of spraying on June 1, 8, and 14 were favorable with wind speeds averaging less than 3 mph. Mean temperatures at the time of spray application on June 1, 8, and 14 were 16, 21, and 17°C respectively. Noticeable rainfall of 0.02, 0.11, and 0.25 in occurred on June 2, 3, and 13 respectively.

Droplet size

Droplet size varied directly with nozzle size. In the Nehantic State Forest plots the droplet size of resmethrin and bioethanomethrin sprayed with the D-2 hollow cone nozzles was 98±47 SDμ (range 48-240μ) and 143±76 SDμ (range 48-384μ) respectively. The droplet size of Dipel and Thuricide-16B sprayed with the D-4 hollow cone nozzles was 207±117 SDμ (range 48-720μ) and 200±81 SDμ (range 48-528μ) respectively. The white cards indicated that all subplots received the spray.

The average droplet size of the Thuricide-16B-dye mixture sprayed in the Salmon River State Forest with D-2 nozzles was 144±90 SDμ. Using D-4 nozzles, the average droplet size was 204±109 SDμ, and using D-6 nozzles it was 329±178 SDμ.

Spray distribution in the canopy

Quantitative assessment of the spray coverage was made by expressing the spray deposits in International Units (IU) of *Bt*/cm^2 of leaf area. There were significant differences of spray deposit between the D-2 hollow cone nozzles and the D-4 and D-6 nozzles but not between the D-4 and D-6 nozzles (Table 1).

Table 1. Calculated International Units (IU) of *B. thuringiensis*/cm^2 of leaf area from plots sprayed with Thuricide-16B with D-2, D-4, and D-6 hollow cone nozzles, Salmon River State Forest. June 14.

Nozzle size	No. trees	$\bar{x}$ IU/cm^2 at 3 crown levels			Whole crown[1]
		Top	Middle	Bottom	$\bar{x}$ IU/cm^2
D-2	6	3.97	3.93	2.02	3.31 a
D-4	6	13.33	11.65	9.33	11.44 b
D-6	5[2]	15.18	11.60	6.10	10.92 b

[1]Means followed by the same letter are not significantly different at 5% level of probability (Duncan's multiple range test).
[2]One tree did not receive any spray and was not included in the analysis.

With all nozzle sizes more spray was deposited on the tops of trees than lower in the canopy, but the amounts were not significantly different.

Gypsy moth egg mass counts

Pretreatment gypsy moth egg mass counts indicated that there was a high population in the test plots (Table 2). Posttreatment egg mass counts showed a marked reduction in all plots whether they were treated or not. In the *Bt* plots, there

Table 2. Mean number of gypsy moth egg masses/acre in Nehantic State Forest before and after application of *B. thuringiensis* and pyrethroids and mean number of eggs/mass after spray application.

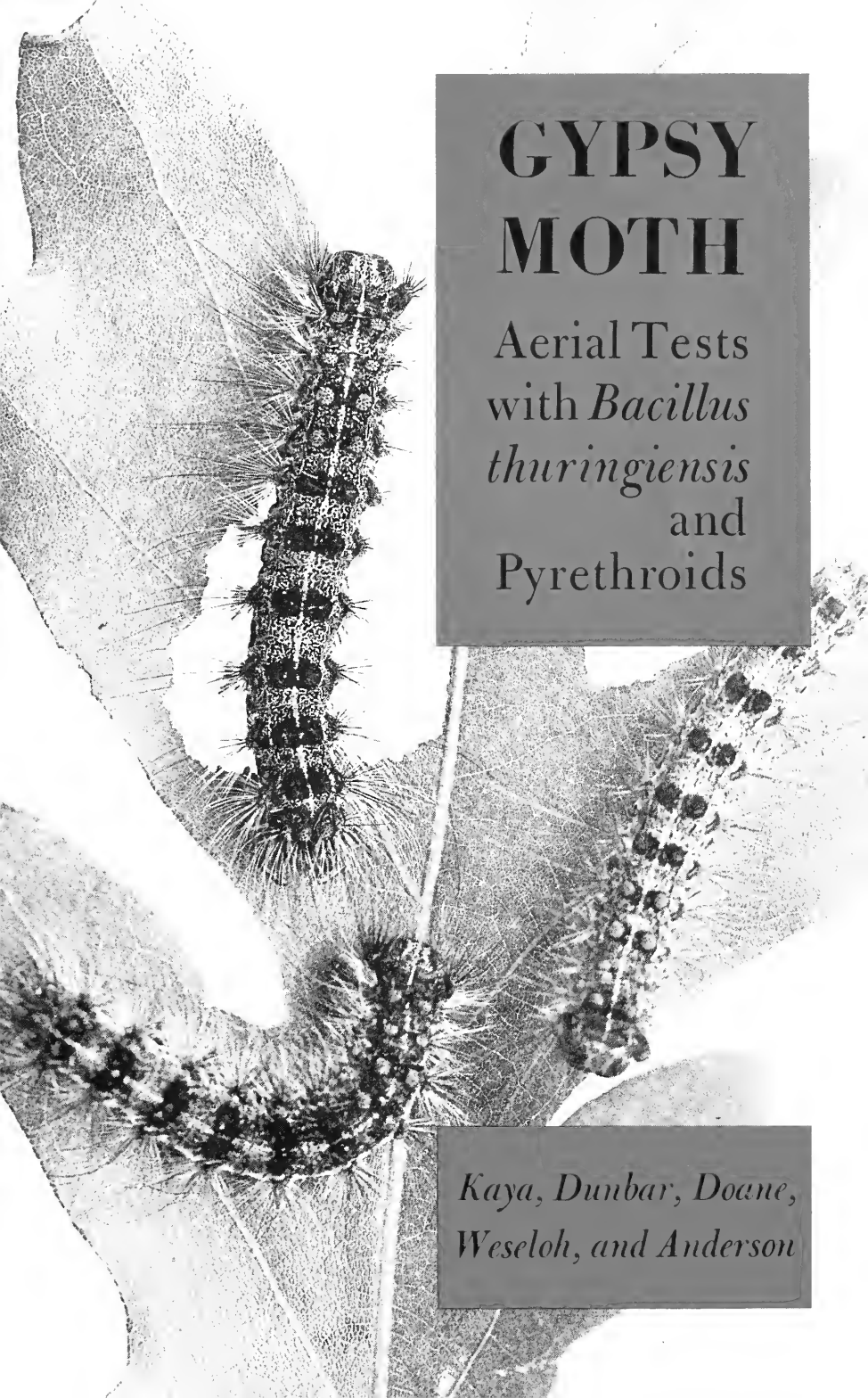
Plot nos.	Treatment	$\bar{x}$ no. egg masses/acre[1]		Posttreatment
		Pretreatment	Posttreatment	$\bar{x}$ no. eggs/mass
		B. thuringiensis		
5 & 7	Dipel	1129	175 a	336 a
4 & 6	Thuricide-16B	1481	239 ab	319 a
9 & 10	Untreated	984	376 b	258 b
		Pyrethroids		
1 & 3	Resmethrin	1999	359 a	295 a
2 & 8	Bioethanomethrin	1042	363 a	296 a
9 & 10	Untreated	984	376 a	258 a

[1]Means within the same column followed by the same letter are not significantly different at the 5% level of probability (Duncan's multiple range test). *B. thuringiensis* and pyrethroid treatments were analyzed separately.

was a significant difference in mean number of egg masses per acre between the Dipel and untreated plots but not between Thuricide-16B and Dipel or the untreated plots. However, there was a significant difference in the mean number of eggs per mass between the *Bt* and untreated plots. Egg masses in the *Bt* plots were larger than those in the untreated plots. In the pyrethroid plots, no significant difference among the treatments was found.

Drop cloth samples of larvae

The number of dead larvae on the drop cloths in the *Bt* plots over a 10-day period is shown in Table 3. Although a few dead



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Summary

The gypsy moth has been a serious problem in Connecticut's forests during the past few years. Together with its caterpillar cousins such as the elm spanworm, the gypsy moth accounted for a record breaking 655,000 plus acres of defoliation in 1971.

In 1972, the state Department of Environmental Protection banned the use of chemical insecticides against the gypsy moth and other defoliators from the air, thus eliminating use of the then most popular aerial treatment—carbaryl or Sevin®. This report discusses tests of two materials that might be substituted if further aerial spraying is desired in Connecticut.

Two formulations of *Bacillus thuringiensis, (Bt),* and two synthetic pyrethroids were tested. *Bt* is acceptable by air in Connecticut because it is a selective microbial insecticide. The pyrethroids are related structurally to pyrethrum, a product of chrysanthemums.

Both *Bt* formulations provided some foliage protection in the aerial tests, but the pyrethroids did not. The knock down rate was high for pyrethroids, but many of the caterpillars recovered, climbed the trees, and continued to feed. The pyrethroids killed many larvae and adults of non-target insects.

Acknowledgments

We thank Misses D. Brown and B. Tracanna and Messrs. W. Gray, G. Hubeny, R. Moore, G. Piontek, K. Welch, and H. Williams for their technical assistance.

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Introduction

Encouraging results from previous ground tests with synthetic pyrethroids and aerial tests with *Bt* led to further tests in Connecticut during 1973. *Bt* is a selective microbial insecticide that is effective against many lepidopterous insects. Synthetic pyrethroids, on the other hand, are broad spectrum in action. In spite of the wide range of insects killed by pyrethroids, their use is advantageous because they degrade rapidly and have low mammalian toxicity.

Previous results with *Bt* have been contradictory. In 1964, tests in Connecticut indicated that *Bt* was not effective from the air, but in 1966 other investigators reported that caterpillar populations were reduced to acceptable levels. Later, in 1971, a formulation mixed with molasses was found effective from the air.

The test plots were forested with mixed hardwoods 40 to 70 feet tall dominated by oak, a favored food of the gypsy moth. The terrain was 140 to 450 feet above sea level. Just prior to spraying, the corners of each plot were marked with helium-filled balloons. Weather conditions were favorable.

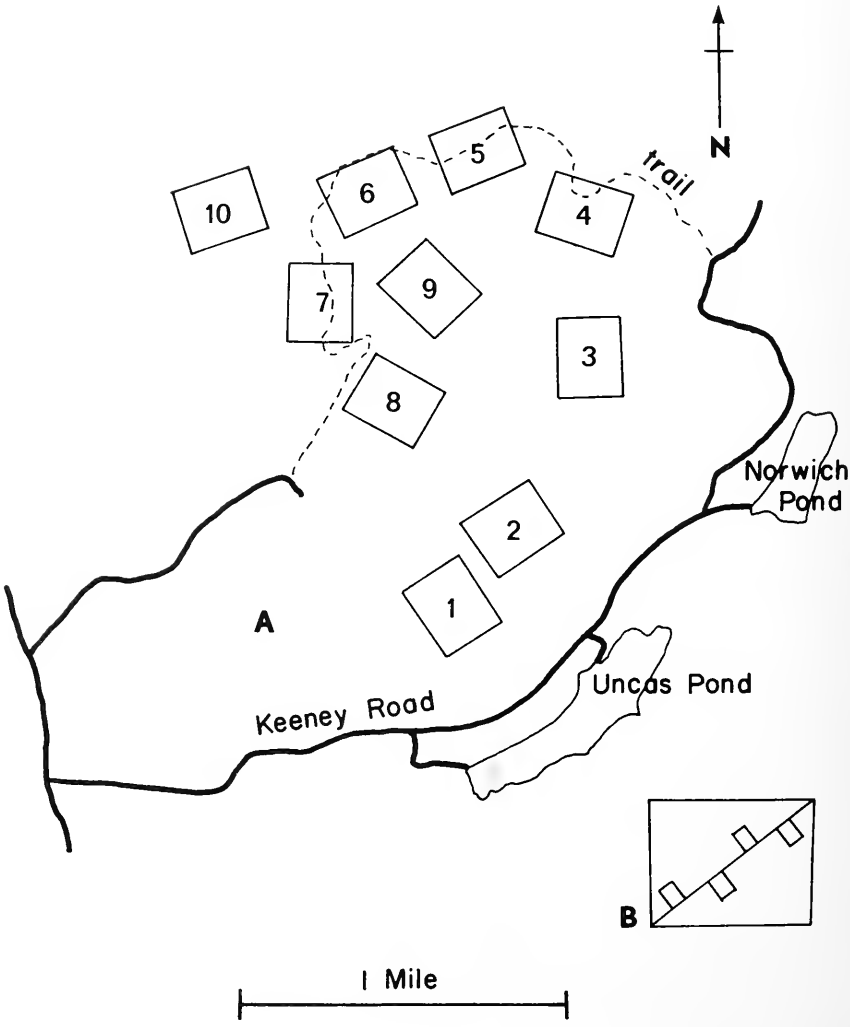

Fig. 1 (A) Map of the test area in Nehantic State Forest and (B) plot showing the layout of subplots.

Materials Tested

The pyrethroids tested were resmethrin (S. B. Penick Co.), and bioethanomethrin (MGK Corp.). Both were formulated in mineral oil at the rate of 0.05 lb. active ingredient per gallon, and were applied at a rate of one gallon per acre. The *Bt* formulations were Thuricide®-16B (Sandoz-Wander, Inc.) and Dipel® (Abbott Laboratories).

Two quarts of aqueous concentrate of Thuricide-16B (8 Billion International Units) were mixed with two quarts of water, and the resulting spray mixture was applied at the rate of one gallon per acre. Dipel was applied at the rate of one pound (7.26 Billion International Units), one quart of Cargill Insecticide Base (molasses), 4 oz. of Nu-Film-17®, and enough water to make a gallon of spray for each acre.

The *Bt* plots were sprayed on June 1 when most of the caterpillars were in their second or third instar. The pyrethroid plots were sprayed on June 8 when most of the caterpillars were in their third or fourth instar. All sprays were applied in the early morning to minimize the effects of wind and convection currents on the spray droplets. The pilot sprayed a swath 75 feet wide along the long axis of the plots about 50 feet above the canopy.

Results

Although a few dead gypsy moth larvae were found in the test plots one day after spraying with *Bt*, the majority died 3 to 10 days after treatment. Observers in the pyrethroid plots reported large numbers of caterpillars were knocked down from the trees within a few minutes, but 5 hours after treatment, many were observed crawling up the trunks of trees.

While Dipel and Thuricide-16B did not completely halt defoliation, both materials provided significantly greater foliage protection than no treatment. There were no apparent differences between the two materials. Neither resmethrin nor bioethanomethrin provided foliage protection.

Net defoliation of oaks was 21 per cent in the Dipel plots and 26 per cent in the Thuricide-16B plots. This compared with net defoliation of 48 per cent in the untreated plots. These results show that some foliage protection can be achieved with aerial application of *Bt*, but the degree of protection is not as great as would be experienced with conventional chemical insecticides.

While there was some foliage protection evident from the

treatments with *Bt*, the numbers of caterpillars in the next generation may not be reduced. The egg masses in treated plots were larger—thus containing more eggs per mass—than egg masses in the untreated plots. The number of egg masses were down considerably in both the treated and the untreated plots. The larger size of egg masses in the *Bt* plots was probably related to reduced competition for food and to a nuclear-polyhedrosis virus epidemic in late June which thinned the populations.

Presumably caterpillar populations in the *Bt*-treated plots were thinned prior to onset of the epidemic, thus larvae had ample food, and were less likely to be infected with the virus. In the untreated plots, however, the population remained dense until the epidemic struck. Undoubtedly under these conditions, crowding, the effect of sublethal doses of nuclear-polyhedrosis virus, and a shortage of suitable foliage upon which to feed resulted in small adults and small egg masses.

Studies of natural enemies of the gypsy moth in the *Bt*-treated plots showed that the tiny wasp *A. melanoscelus* was a more effective parasite in the Dipel-treated plots than in the Thuricide-16B plots. No difference was noted in the pyrethroid plots. In the *Bt* plots, Lepidoptera and Coleoptera were found on drop cloths more frequently than in untreated plots. Lepidoptera, Coleoptera, Hymenoptera, Diptera, and Hemiptera were more abundant on drop cloths in the pyrethroid-treated plots than in the untreated ones. More species were recovered from the resmethrin plots than from the bioethanomethrin plots.

[A longer version of this bulletin containing more technical data is available from Publications, Box 1106, New Haven, CT. 06504. Ask for Bulletin 744.]

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Paul E. Waggoner
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gypsy moth larvae were on the cloths 1 day after application, the majority died 3 to 10 days after treatment.

Table 3. Total number of dead gypsy moth larvae collected on drop cloths at various time intervals following application of *B. thuringiensis* on June 1.

Plot nos.	Treatment	Total no. dead larvae days after spraying					$\bar{x}$/cloth/day[1]
		1	3	5	7	10	
4 & 6	Dipel	28	221	319	296	160	8.5 a
5 & 7	Thuricide-16B	32	168	350	267	117	7.8 a
9 & 10	Untreated	7	8	21	66	36	1.2 b

[1]Means followed by the same letter are not significantly different at 5% level of probability (Duncan's multiple range test).

The pyrethroids, on the other hand, knocked the gypsy moth larvae from the trees within a few minutes after application. Within 5 hr, over 50 gypsy moth larvae/cloth were counted (Table 4). Counts taken 30 hr after treatment showed sig-

Table 4. Mean number of gypsy moth larvae/drop cloth 5 and 30 hrs after application of pyrethroids on June 8.

Plot nos.	Treatment	$\bar{x}$ no. larvae/cloth[1]	
		5 hours	30 hours
1 & 3	Resmethrin	57.2 a	6.5 b
2 & 8	Bioethanomethrin	54.9 a	10.9 a
9 & 10	Untreated	1.5 b	1.3 c

[1]Means within a column followed by the same letter are not significantly different at the 5% level of probability (Duncan's multiple range test).

nificantly more larvae on the cloths in the bioethanomethrin plots than in the resmethrin or untreated ones. Significantly more larvae were found in the resmethrin plots than in the untreated plots. However, considerably fewer larvae were found at the 30 hr count than at 5 hr indicating the high contact and low residual activity of these materials.

Drop cloth samples of frass

The average dry weight of frass per cloth for the 3-day collecting period is given in Table 5. Quantities of frass collected

Table 5. Average weight (gm) of frass/drop cloth under oaks from June 22-25 from gypsy moth larvae feeding in treated and untreated plots.

Plot nos.	Treatment	gm frass/drop cloth[1]
4 & 6	Dipel	29.8 a
1 & 3	Resmethrin	37.0 ab
5 & 7	Thuricide-16B	38.7 ab
2 & 8	Bioethanomethrin	47.6 bc
9 & 10	Untreated	59.2 c

[1]Means followed by the same letter are not significantly different at the 5% level of probability (Duncan's multiple range test).

in the Thuricide-16B, resmethrin and Dipel plots were significantly less than the untreated plots. There was no significant difference between the bioethanomethrin plots and the untreated plots.

Branch terminal counts of larvae

Analysis of pretreatment counts of gypsy moth larvae on branch terminals of oak showed that larvae were evenly distributed throughout the *Bt* and untreated plots on May 22 and the pyrethroid and untreated plots on June 4 (Table 6). Differences observed between the sampling dates are due to the change in behavior of the older larvae which tend to move from foliage to sheltered places during the day (Forbush and Fernald 1896, Leonard 1970).

There were significantly fewer gypsy moth larvae on branch terminals in the treated plots than in the untreated plots 6 days after application of *Bt* (Table 6). Extensive observations were made in Plot 6 to determine the effects of *Bt* on the behavior of gypsy moth larvae. Many dead larvae were counted on leaves of the understory oak. On 40 branch terminals in this plot 55 living larvae and 57 dead ones were found 6 days after spraying. Many dead larvae were also observed on the forest litter. In addition, many partially paralyzed larvae were found with their crochets caught in silken webbing on the leaves and branches.

Table 6. Mean number of gypsy moth larvae on ten 2 ft branch terminals of oaks before and after treatment with *B. thuringiensis* and pyrethroids.

Plot nos.	Treatment	Pretreatment	Posttreatment[1]		
			4 days	6 days	11 days
		B. thuringiensis[2]			
4 & 6	Dipel	73.1	–	17.3 a	2.5 a
5 & 7	Thuricide-16B	88.1	–	17.2 a	8.6 a
9 & 10	Untreated	74.1	–	40.7 b	34.7 b
		Pyrethroids[3]			
1 & 3	Bioethanomethrin	49.0	18.6 a	–	–
2 & 8	Resmethrin	40.0	28.1 ab	–	–
9 & 10	Untreated	45.0	34.7 b	–	–

[1]Means within a column followed by the same letter are not significantly different at 5% level of probability (Duncan's multiple range test). *B. thuringiensis* and pyrethroid treatments analyzed separately.
[2]Pretreatment counts taken on May 22. Sprays applied on June 1.
[3]Pretreatment counts taken on June 4. Sprays applied on June 8.

Significantly fewer larvae were counted on branch terminals in the *Bt* plots 11 days after treatment than in the untreated plots.

Immediately following the application of pyrethroids, observers in the plots reported that large numbers of larvae were knocked down from the trees, but 5 hr after application, many larvae were observed crawling up the trunks of trees. Apparently, many of these larvae survived the treatment because counts taken 4 days later showed a considerable number of living larvae on the branch terminals. There were significantly fewer larvae on branch terminals in plots treated with bioethanomethrin than in plots treated with resmethrin or in the untreated plots (Table 6).

Burlap bands

Significantly fewer gypsy moth larvae and pupae were found under burlap bands in all treated plots in comparison to untreated plots, but there were no significant differences among the treatments (Table 7).

Defoliation

Defoliation data are expressed as percent defoliation per tree. Final defoliation represents the average maximum defoliation per tree, while net defoliation represents the difference between final and pretreatment defoliation.

Table 7. Mean number of gypsy moth larvae and pupae under burlap bands/tree, June 28-29.

Plot nos.	Treatment	$\bar{x}$ no. larvae and pupae/burlap band[1]
4 & 6	Dipel	4.7 a
5 & 7	Thuricide-16B	6.7 a
1 & 3	Resmethrin	7.5 a
2 & 8	Bioethanomethrin	8.1 a
9 & 10	Untreated	19.0 b

[1]Means followed by the same letter are not significantly different at the 5% level of probability (Duncan's multiple range test).

Pretreatment defoliation had proceeded to approximately 40% before the *Bt* sprays were applied. While Dipel and Thuricide-16B did not completely stop defoliation, they did provide significantly greater foliage protection than no treatment (Table 8). There were no apparent differences in defoliation in the Dipel or Thuricide-16B plots.

Table 8. Percent defoliation observed per oak tree after cessation of larval feeding in Nehantic State Forest.

Plot nos.	Treatment	$\bar{x}$ defoliation/tree		
		Pretreatment	Final	Net[1]
		B. thuringiensis[2]		
4 & 6	Dipel	42.8	64.0	21.2 a
5 & 7	Thuricide-16B	34.9	61.1	26.2 a
9 & 10	Untreated	36.8	84.6	47.8 b
		Pyrethroids[3]		
1 & 3	Resmethrin	45.4	75.0	29.6 a
2 & 8	Bioethanomethrin	43.7	77.2	33.5 a
9 & 10	Untreated	51.6	84.6	33.0 a

[1]Means followed by the same letter are not significantly different at the 5% level of probability (Duncan's multiple range test). *B. thuringiensis* and pyrethroid treatments analyzed separately.
[2]Pretreatment defoliation estimates were made May 29 and 30. Sprays applied on June 1.
[3]Pretreatment defoliation estimates were made June 5 and 8. Sprays applied on June 8.

Defoliation of trees in plots sprayed with pyrethroids had increased since pretreatment defoliation estimates were made for the *Bt* plots. Neither resmethrin nor bioethanomethrin provided any foliage protection (Table 8).

Effect on natural enemies of the gypsy moth

Six parasitoids were reared from collected immature gypsy moths including the bracon, *A. melanoscelus*, the ichneumon, *Phobocampe disparis* (Viereck), the tachinids, *Compsilura concinnata* (Meigen), *Parasitigena agilis* (Robineau-Desvoidy), *Blepheripa scutellata* (Robineau-Desvoidy), and the chalcid, *Brachymeria intermedia* (Nees). Analysis was made only for *A. melanoscelus* because percent parasitism for the other parasitoids was less than 5% in all plots. Percent parasitism for *A. melanoscelus* was significantly higher in the Dipel-treated plots than in all the other plots (Table 9). There was no difference between the pyrethroid and untreated plots.

Table 9. Average percent parasitism by *A. melanoscelus* of gypsy moth larvae and mean number of *A. melanoscelus* cocoons and *C. sycophanta* larvae/burlap band in plots treated with *B. thuringiensis* and pyrethroids and in untreated plots.[1]

Plot nos.	Treatment	% parasitism by	$\bar{x}$ no./burlap band	
		A. melanoscelus	*A. melanoscelus* cocoons	*C. sycophanta* larvae
4 & 6	Dipel	20.6 a	8.1 a	0 a
5 & 7	Thuricide-16B	7.0 b	4.7 b	0.3 ab
1 & 3	Resmethrin	0.7 b	0.8 c	.6 ab
2 & 8	Bioethanomethrin	.9 b	1.2 c	1.4 b
9 & 10	Untreated	1.3 b	.8 c	2.9 c

[1]Means within the same column followed by the same letter are not significantly different at the 5% level of probability (Duncan's multiple range test).

The number of *A. melanoscelus* cocoons found under the burlap bands was significantly higher in the Dipel and Thuricide-16B plots than in the untreated ones, and significantly higher in the Dipel plots than in the Thuricide-16B plots (Table 9). No difference was noted in the pyrethroid plots. Larval counts of *C. sycophanta* were significantly lower in plots treated with *Bt* or pyrethroids than in the untreated plots.

Effect on nontarget insects — Drop cloth counts

The most common nontarget insects found on the drop cloths are shown by orders in Table 10. Adult insects in the orders Mecoptera, Plecoptera, Orthoptera, Psocoptera and Odonata, and 2 spiders were also collected in the pyrethroid plots.

Table 10. Total numbers of nontarget insects found on the drop cloths after spray application of *B. thuringiensis* and pyrethroids.

	B. thuringiensis[1]			Pyrethroids[1]		
Order	Thuricide-16B	Dipel	Untreated[2]	Resmethrin	Bioethanomethrin	Untreated[2]
Lepidoptera	32 a	35 a	3 b	227 a	236 a	2 b
Hymenoptera	6	4	6	33 a	50 a	2 b
Hymenoptera (Parasitoids)	1	0	2	10 a	15 a	2 a
Diptera	9	9	4	48 a	45 a	3 b
Diptera (Parasitoids)	0	1	1	5	3	1
Hemiptera	2	1	0	36 a	45 a	0 b
Coleoptera	17 ab	21 a	6 b	56 a	72 a	6 b

[1]Numbers in the same row followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test). *B. thuringiensis* and pyrethroid treatments were analyzed separately.
[2]Total for untreated plots for *B. thuringiensis* comparisons are for a 10-day period and for the pyrethroid comparisons are for a 4-day period.

As with the gypsy moth, most of these were knocked down within 5 hr after application. Although none of these insects was moving, it is possible that some of them would have recovered had they been left in place. For example, observers in the plots reported that *C. sycophanta* adults were knocked down from trees but recovered without any apparent adverse effects within 2 hr after treatment. In the *Bt* plots, the numbers found were more or less uniformly distributed over the collection dates.

If more than 10 insects belonging to a single order were knocked down in the plots, analyses of variance were performed. In the *Bt* plots, Lepidoptera and Coleoptera were more abundant than in the untreated ones while in the pyrethroid plots, Lepidoptera, Coleoptera, Hymenoptera, Diptera, and Hemiptera were more abundant than in the untreated ones. More species of insects were recovered from the resmethrin plots than from the bioethanomethrin plots.

Eleven adult specimens of 4 species of gypsy moth parasitoids were found on the drop cloths. These were *A. melanoscelus, B. intermedia, P. agilis,* and *B. scutellata.* Two ichneumonid cocoons identified as *Phobocampe* sp. and a tachinid puparium close to *Compsilura* sp. were also found on the drop cloths. Because of the low numbers no analysis was made.

Discussion

Pyrethroids did not protect the foliage. Net defoliation was between 29-33% in the treated plots and 33% in the untreated plots. These data contrast with those of Dunbar and Doane (1973) who reported good foliage protection from ground spraying with a mistblower. Although the knock down rate from aerial application was high, many gypsy moth larvae recovered from the pyrethroid treatments and continued their feeding. Terminal counts of larvae, defoliation estimates, and direct observations verified that a large proportion of larvae survived the treatments. The low rate, low residual activity and large droplet size of the spray may account for the lack of control. With contact insecticides, Himel (1969) indicated that the optimum size for spray droplets is in the range of 20μ diameter, while droplets of 50-100μ diameter provide marginal efficiency. The droplet sizes of the pyrethroids sprayed with the D-2 hollow cone nozzles were 5-7 times the optimum size. In future aerial tests, a higher rate and smaller droplet size may provide effective control.

A number of formulations of *Bt* have been aerially tested in the northeastern United States with variable results (Lewis *et al.* 1962, Doane and Hitchcock 1964, Lewis and Connola 1966, Secrest and McLane 1971, and Dunbar *et al.* 1973). Recent improvements in formulations and use of a different strain of *Bt* (HD-1 strain) have increased the effectiveness of this microbial insecticide. In tests conducted in 1972, Dunbar *et al.* (1973) reported that net defoliation for oaks in plots treated with Thuricide HPC or Thuricide-16B was between 26-39% compared with 52% in the untreated plots. In 1973, net defoliation of oaks

was 21% in the Dipel plots and 26% in the Thuricide-16B plots. Net defoliation in the untreated plots was 48%. These results show that some foliage protection can be achieved with aerial application of *Bt*; however, the degree of protection did not compare with aerial application of conventional chemical insecticides (Doane and Schaefer 1971).

Small droplets are optimum with contact insecticides (Himel 1969), but droplet size must be kept large to minimize drift to prevent contamination of nontarget areas (Lofgren 1971). Paradoxes such as these make aerial application of insecticides difficult. The spray coverage test with Thuricide-16B-dye mixture showed that better leaf coverage in the canopy was obtained with larger droplets. Because only 1 pass was made, the difference in coverage may have resulted from the smaller droplets drifting away from the plot. Since this difference may be an artificial one, more critical studies of spray coverage in forest situations are needed.

Application of *Bt* from the air may not reduce the next generation of gypsy moth. Dunbar *et al.* (1973) reported that gypsy moth egg mass counts increased markedly in plots treated with *Bt* as well as in the untreated plots. Conversely, Doane and Hitchcock (1964) showed that egg mass counts decreased in all plots whether they were treated with *Bt* or not. Our data also showed a decrease in egg mass counts in all plots. These varied results indicate that population increase or decrease in the next generation is not dependent on aerial application of *Bt*.

Egg masses in plots previously treated with chemical insecticides were larger than those in untreated plots (Doane 1968). Similar results were obtained in plots treated with *Bt*. The difference between *Bt* and untreated plots is probably related both to reduced competition and to an epizootic of nuclear-polyhedrosis virus which occurred in late June toward the end of larval feeding. Presumably, larval populations in plots treated with *Bt* were thinned before the onset of the epizootic. In contrast to larvae in untreated plots, survivors in the *Bt* plots had ample foliage on which to feed and were less likely to contact virus-infected larvae. Adults emerging in the *Bt* plots were healthy and deposited relatively large egg masses. In the untreated plots the population remained dense until the epizootic decimated the population. Undoubtedly under these conditions, crowding, effect of sublethal dosages of nuclear-polyhedrosis virus and the shortage of suitable foliage resulted in small larvae, small adults and small egg masses. Inasmuch as pyrethroids

were ineffective, small egg masses were produced in these plots. Thus, it appears that both chemical and biological insecticides influence egg mass size if they are effectively applied to populations that are beginning to collapse from density-dependent factors such as the nuclear-polyhedrosis virus. Both the rate of disease transmission and intraspecific competition are greatly reduced resulting in healthier, larger individuals which lay more eggs.

The results obtained on percent parasitism of *A. melanoscelus* and the counts of *A. melanoscelus* cocoons under burlap seem to indicate that *Bt* had beneficial effects on this parasitoid. However, the percent parasitism data may be misleading because fewer numbers of gypsy moth larvae were present in the *Bt* plots than in the untreated ones after spraying. With fewer gypsy moth larvae available, percent parasitism should increase as suggested by Dunbar *et al.* (1973). It is possible that differential mortality of gypsy moth larvae caused by nuclear-polyhydrosis virus affected these percentages.

On the other hand, numbers of cocoons counted under burlap were highest in the *Bt* plots. Cocoon counts are themselves an estimate of numbers of parasitoids rather than relative proportions and cannot be explained in the same manner as percent parasitism unless differential virus mortality occurred between the *Bt* and untreated plots. The burlap counts suggest that *Bt* sprays benefited *A. melanoscelus*. It is possible that additives such as molasses in the Dipel mixture attracted adult parasitoids into the plots or extended the lives of the parasitoids. These different interpretations of the results between percent parasitism and burlap cocoon counts mean that any conclusion regarding the effects of *Bt* on adult *A. melanoscelus* activity needs further investigation.

As expected, pyrethroids had a greater effect on nontarget insects than *Bt*. A fairly high number of Coleoptera in the families Scarabeidae, Elateridae, Lampyridae, Cleridae and Cantharidae were found on the drop cloths in the *Bt* plots. No explanation is offered for these findings.

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