Gypsy Moth Management in Suburban Parks: Program Evaluation[1, 2]

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ABSTRACT A specialized gypsy moth management program for urban parks was implemented in six state and county parks and the Beltsville Agricultural Research Center (BARC) in Maryland in 1990 and 1991. Decisions to treat with aerial applications of *Bacillus thuringiensis* Berliner (one or two applications) or diflubenzuron or to not treat were based on gypsy moth egg mass density, egg mass size, percentage of susceptible host trees, amount of previous defoliation, and the potential non-target effects of diflubenzuron. A total of 1025 and 1926 ha in the management program was treated with one and two applications of *B. thuringiensis,* respectively, and 1204 ha were left untreated. One block of 47 ha was treated with diflubenzuron. Larval mortality as a result of the treatments averaged 76 and 83% in areas treated with one and two applications of *B. thuringiensis,* respectively, and 87% in the area treated with diflubenzuron. Some noticeable defoliation occurred under all treatments. The greatest amount of defoliation (29% of total area) occurred in a management unit with an average initial egg mass density of 49,250/ha that was treated twice with *B. thuringiensis.* Comparisons with adjacent areas not included in the management program indicated that even when defoliation did occur, it was reduced both in severity and extent by the treatments. This evaluation of the gypsy moth management program that was developed to provide a high level of foliage protection in suburban parks indicated that a number of improvements can be made in the program. However, without more efficacious intervention tactics, the goal of preventing noticeable defoliation in any part of a management unit may not be achievable solely with biological agents where extremely high gypsy moth population densities are present.

KEY WORDS Insecta, gypsy moth, *Bacillus thuringiensis,* diflubenzuron.

In 1991, 69% of the 454,482 ha of primarily forested environments treated in cooperative programs to control gypsy moths were treated with one application of *Bacillus thuringiensis* (Gypsy Moth News 1991). A three-year study of the treatment-monitoring data base on gypsy moth suppression in the northeastern United States (Twardus and Machesky 1990) reported that defoliation goals were met 74%, and population reduction goals 47%, of the time when one application of *B. thuringiensis* was used. Such results are probably acceptable in forested environments. However, a higher level of success is desired for high-value park

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and shade trees in urban/suburban areas. There is also considerable public interest in the use of environmentally benign pest control materials in such areas and the need for closer scrutiny in the way in which the gypsy moth is dealt with is recognized (Ravlin et al. 1987).

In 1988 and 1989, a gypsy moth management program was developed for suburban parks and park-like properties that included a series of biological evaluations of the operational use of *B. thuringiensis* and diflubenzuron (Dimilin®) (Webb et al. 1991). This program emphasized both more intensive sampling and more applications of *B. thuringiensis* than are normally utilized in forested situations, and because of the higher value of trees in the park setting, higher control costs can be justified. A decision guide particularly for use in application of *B. thuringiensis* was developed as part of that program. The guide recommended one or two applications, depending on egg mass density, egg mass size, percentage of susceptible host trees, and previous defoliation. However, some defoliation occurred on untreated lands or where only one application of *B. thuringiensis* was used. In response to these program shortcomings, the present research was conducted in 1990 and 1991 to evaluate the *B. thuringiensis*-based management program against higher density populations and to continue some comparative evaluations of *B. thuringiensis* and diflubenzuron.

The objectives of this study were: (1) continue evaluation of the specialized gypsy moth management program, especially the effectiveness of one versus two applications of *B. thuringiensis* as prescribed under the decision guide; (2) evaluation of the effectiveness of *B. thuringiensis* against high gypsy moth populations; (3) further investigation and documentation of the reasons for failure to prevent noticeable defoliation on any part of the management unit (defoliation becomes noticeable during aerial sketch mapping when > 30% of the leaf surface area has been removed [J. Ghent, personal communication]); and (4) identification of specific areas in which to continue research on means of correcting problems that may lead to defoliation.

Materials and Methods

Management units were selected for inclusion in this study if preliminary surveys indicated potentially damaging gypsy moth populations (i.e., some survey points with > 1000 egg masses/ha; high percentage of susceptible foliage; medium-large egg masses [>400 egg/mass]; and limited previous defoliation). In 1990, the management units consisted of the Beltsville Agricultural Research Center (BARC), in Prince Georges County, and three Montgomery County parks (Little Bennett, Rachel Carson, and Blockhouse Point) included in a pervious study (Webb et al. 1991). In 1991, the management units consisted of BARC, and three state parks on Maryland's Eastern Shore. In addition, areas contiguous with, but outside, the boundaries of BARC (1990) and of Linkwood State Park (1991) were selected for partial evaluation.

Egg mass surveys were conducted in all management units. A 300-m grid was superimposed over the forested areas of each management unit. A 0.01-ha (1/40-acre) fixed plot egg mass survey, as described by Kolodny-Hirsch (1986), was conducted at each intersection of lines of the grid. However, when the grid intersection occurred at a point in which the tree species composition was not representative of the tree stand in general, the center of the survey plot was moved up to 75 m away to a location more representative of the surrounding area. Within each survey plot, all of the egg masses were counted. All egg masses within reach from the ground were examined to determine whether they were new (unhatched) or old (already hatched). The ratio of new to old egg masses within reach from the ground was used to adjust the total egg mass count to an estimate of the number of new egg masses per survey plot.

The lengths of the first five egg masses examined in each plot were recorded and used to calculate an estimate of the mean number of eggs per mass, using the formula developed in Moore and Jones (1987):

$$y = 1.58x + 0.29,$$

where $y = \log_{10}$(number of eggs per mass), $x = \log_{10}$(length of the mass in mm), and the intercept term is expressed in log units. Percent canopy cover and percent Class I host trees (Wilson and Fontaine 1978) were recorded for each survey plot.

Areas to receive single or double applications of *B. thuringiensis* were determined by dividing the management units into blocks of from 2 to 232 ha. The decision guide from Webb et al. (1991) was used to assign treatments to blocks based on egg mass density, egg mass size, previous defoliation, and percentage of Class I host trees. Diflubenzuron use was restricted to one block on BARC in 1990.

In 1990, *B. thuringiensis* (Foray® 48B, Novo Laboratories Inc., Danbury, CT; 60 Billion International Units [BIU]/ha in water at an application volume of 9.3 liters/ha) and diflubenzuron (Dimilin, Uniroyal Chemical Co., Middlebury, CT; 69 g [AI]/ha in water at an application volume of 7.0 liters/ha) were applied aerially with a DC-3 and a Twin Beech fixed-wing aircraft. In 1991, *B. thuringiensis* (Foray 48B; 74[BIU]/ha in water at an application volume of 7.0 liters/ha) and diflubenzuron (Dimilin; 69 g [AI]/ha in water at an application volume of 7.0 liters/ha) were applied aerially with a Bell 204 helicopter. The second application of *B. thuringiensis* was made 3 to 5 d after the first.

Treatment efficacy was monitored in two ways in both 1990 and 1991. First, larval mortality was assessed as described in Webb et al. (1991). The number of early (first and second) instar larvae occurring on 20 randomly located evaluation sites was determined from 1 to 3 d before the first spray application and again from 2 to 4 d after the last application. Evaluation sites consisted of marked lengths of oak (*Quercus* spp.) saplings on lower branches. For comparison, control evaluation sites were selected in nearby untreated areas of the management unit. At the time of the second count, larvae were placed on artificial gypsy moth diet (Bell et al. 1981) in small plastic cups and held at room temperature for 14 d. Total mortality was calculated as the difference between the initial number of larvae on the evaluation site and the number of live larvae remaining after 14 d. Treatment mortality was calculated using Abbott's formula (Abbott 1925) as modified by Rosenheim and Hoy (1989) by comparing larval numbers before and after the spray in treated and nearby untreated areas. Second, defoliation was assessed through aerial sketch mapping and infrared photography interpretation.

In 1990 at BARC and in an adjacent diflubenzuron spray block in Greenbelt, MD, burlap bands were placed around oak trees to assess differences in gypsy moth density in areas treated with diflubenzuron and contiguous areas treated with two applications of *B. thuringiensis*. After all adult emergence had occurred, the number of pupae from which adults had emerged was determined for each burlap. The diameter at breast height (dbh) of each banded tree was measured, and pupal numbers were expressed per cm of dbh.

Results

Over the two years of the study, 1026 ha were sprayed once and 1926 ha were sprayed twice with *B. thuringiensis,* 47 ha were sprayed with diflubenzuron, and 1204 ha were left unsprayed (Table 1). In 1990, egg mass densities at Little Bennett were relatively high, but this area had experienced potentially defoliating populations for the previous two years (Webb et al. 1991), and populations generally appeared to be in decline. Populations at BARC in 1990 also had been high the previous two years but, based on large egg mass size, remained vigorous for a third year. In 1991, populations at BARC were high in some areas, but were in decline in others. Populations at Blockhouse Point and Rachel Carson had been high in 1989 (Webb et al. 1991), and measurements of egg mass size in 1990 indicated that those populations continued to be vigorous. Two of the three management units on the Eastern Shore of Maryland included in 1991 had particularly high egg mass densities, with extremely high densities (49,250/ha) at Linkwood; defoliation had not occurred in any of these three management units the previous year.

Percentage mortality of larvae at evaluation sites was corrected for estimated natural mortality as measured in nearby untreated sites (Table 2). Corrected mortality ranged from 64 to 87% with one *B. thuringiensis* application and from 76 to 95% with 2 applications. Corrected mortality in the one diflubenzuron-treated block was 87%.

Table 3 shows pre- and post-season egg mass densities in the diflubenzuron spray block at BARC and another diflubenzuron spray block adjacent to BARC in the city of the Greenbelt, all in Prince Georges County, as well as in areas on BARC that adjoined the diflubenzuron spray blocks and were treated with two applications of *B. thuringiensis.* There was an 83% reduction in egg mass numbers in the diflubenzuron spray block, but numbers of egg masses increased by 28% in the *B. thuringiensis*-treated areas. The number of pupae from which adults successfully emerged was 1.7 per cm of dbh in the *B. thuringiensis*-treated areas versus 0.2 per cm of dbh in the diflubenzuron-treated area. These data indicate that the field evaluation site assay used in this study, based on pre-and post-treatment counts of the earlier larval instars, may underestimate mortality caused by diflubenzuron, perhaps because of the delayed effects of this insect growth regulator (White et al. 1981).

BARC (1990) was the only management unit in which defoliation occurred in an untreated area (Table 4). The estimated egg mass density was low for this area, indicating that the egg mass survey method had probably underestimated actual egg mass density. Defoliation occurred on two of the management units in areas treated with one application of *B. thuringiensis,* and on three management

Table 1. Size of areas treated with *Bacillus thuringiensis* (B.t.) and pre-season egg mass density for six parks and the Beltsville Agricultural Research Center (BARC) operating under a specialized gypsy moth management program, 1990-1991.

	Untreated		1 B.t. application		2 B.t. applications	
Management Unit	No. hectares	No. egg masses/ha	No. hectares	No. egg masses/ha	No. hectares	No. egg masses/ha
1990						
Little Bennett	816	1000	134	500	159	5000
Rachel Carson	0	–	0	–	208	31500
Blockhouse Point	48	500	0	–	94	14750
BARC	132	1000	48	500	507	7750
1991						
Wye Island	0	–	38	7750	54	14250
Linkwood	0	–	0	–	295	49250
Seth Demo Forest	0	–	64	2000	0	–
BARC	208	500	742	1250	609	4000
Total	1204		1026		1926	

A dash (–) indicates that the treatment was not included at the specified location.

units in areas treated twice with *B. thuringiensis*. In two cases the relative effectiveness of the management program could be quantified with regard to defoliation prevention by making comparisons with untreated areas. At BARC in 1990, and at Linkwood in 1991, the areas included in the management program were contiguous with unmanaged forested areas that, because of their proximity, were presumably faced with similar gypsy moth populations. At BARC, both moderate (30-60%) and severe (61-100%) defoliation were greater in the unmanaged areas (Table 5). At Linkwood, fewer hectares were moderately defoliated in the unmanaged portion, but more hectares were severely defoliated. Population density was extremely high at Linkwood (mean pre-season egg mass density was 49,250/ha), and two *B. thuringiensis* applications did not prevent defoliation in the managed area. However, the differences between the managed and unmanaged areas indicate that the *B. thuringiensis* treatments substantially reduced the amount of severe defoliation.

Discussion

Based on the results from four years of evaluation of the specialized program designed for management of gypsy moths in urban parks (Table 6), other results discussed in this paper, information published by Webb et al. (1991), and the general experience associated with the evaluations in 1990 and 1991,

Table 2. Percent mortality (corrected for natural mortality) ± standard error of larvae after application of *Bacillus thuringiensis* (B.t.) or diflubenzuron based on counts of larvae at evaluation sites, 1990-1991.

	% mortality ± SEM		
Management Unit	1 B.t. application	2 B.t. applications	Diflubenzuron
1990			
Little Bennett	–	85 ± 19	–
Rachel Carson	–	76 ± 13	–
Blockhouse Point	–	80 ± 20	–
BARC	64 ± 25	81 ± 19	87 ± 8
1991			
Wye Island	78 ± 11	82 ± 10	–
Linkwood	–	95 ± 7	–
Seth Demo Forest	87 ± 14	–	–
Average	76	83	87

A dash (–) indicates that the treatment was not included at the specified location.

several observations can be made that can be useful in identifying problems, establishing research needs, and making improvements in operational programs for managing gypsy moths in urban areas.

Observations. The field assay employed in this study and in Webb et al. (1991) indicated greater early instar larval mortality after two compared to one application of *B. thuringiensis.* However, because areas treated twice with *B. thuringiensis* generally had higher pre-treatment larval densities, some of the increased larval mortality in these areas may be associated with higher levels of mortality due to the gypsy moth nuclear polyhedrosis virus (NPV). Mortality from NPV is positively correlated with gypsy moth population density (Woods and Elkinton 1987). Furthermore, pupal counts and post-season egg mass counts indicated that the results of the early larval instar assays conducted over a short period of time were not reflected in the more extended comparative effects of *B. thuringiensis* and diflubenzuron. Clearly, a more dependable field assay is needed to reliably assess treatment effects on gypsy moth populations. The results show that treatments with *B. thuringiensis* did reduce defoliation, severe defoliation in particular, where extremely high gypsy moth populations were present. Because severe defoliation is generally believed to be significantly more damaging to oak trees than is moderate defoliation (Wargo 1981), some benefit from treatments with *B. thuringiensis* can be expected, even when the level of foliage protection obtained is less than desired.

Table 3. Effects of application of *Bacillus thuringiensis* (B.t.) and diflubenzuron on numbers of gypsy moth egg masses and pupae. Prince Georges County, MD, 1990.

	2 B.t. applications	Diflubenzuron
Pre-season egg masses/ha ± SEM	7698 ± 2732	3788 ± 1018
Post-season egg masses/ha ± SEM	9868 ± 2290	630 ±188
% change in egg masses/ha	+28	-83
Total pupae/cm of dbh ± SEM	1.7 ± 0.3	0.20 ± 0.12

Table 4. Percentage of hectares with noticeable defoliation (> 30% of leaf surface removed) in management units operated under a specialized gypsy moth management program in which *Bacillus thuringiensis* (B.t.) was the primary intervention method, 1990-1991.

Management Unit	% of ha with noticeable defoliation		
	Untreated	1 B.t. application	2 B.t. applications
1990			
Little Bennett	0	0	0
Rachel Carson	–	–	0
Blockhouse Point	0	–	0
BARC	16	19	6
1991			
Wye Island	–	0	20
Linkwood	–	–	29
Seth Demo Forest	–	3	–
BARC	0	0	0

A dash (–) indicates that the treatment was not included at the specified location.

Table 5. Comparison of defoliation in experimental areas treated with *Bacillus thuringiensis* (B.t.) or diflubenzuron and in adjacent untreated areas, 1990-1991.

	No. hectares		% of ha with noticeable defoliation*			
			Untreated		Treated	
Area	Treated	Untreated	Moderate	Severe	Moderate	Severe
BARC/SSC**	602	163	34	8	8	0
Linkwood/Private†	295	363	17	23	32	3

* Noticeable defoliation occurs when > 30% of the leaf surface has been removed.

** Beltsville Agricultural Research Center (BARC) treated with one (48 ha) or two (507 ha) applications of B.t. or diflubenzuron (47 ha); adjacent Secret Service Center (SSC) untreated. 1990.

† Linkwood State Wildlife Management Center treated with 2 applications of B.t.; adjacent private lands untreated. 1991.

Table 6. Management unit, mean egg masses (thousands/ha) before application of *Bacillus thuringiensis* (B.t.) and diflubenzuron, percent larval mortality due to the treatment, and percent of ha with noticeable (> 30% of leaf surface removed) defoliation in suburban forests, 1988-1991).

	Untreated		1 B.t. application			2 B.t. applications			Diflubenzuron		
Management Unit	No. egg masses /ha × 10^{-3}	% def.	No. egg masses /ha × 10^{-3}	% corrected mort.	% def.	No. egg masses /ha × 10^{3}	% corrected mort.	% def.	No. egg masses /ha × 10^{3}	% corrected mort.	% def.
1988											
Little Bennett	2.0	0	8.5	58	0	9.5	81	0	–	–	–
1989											
Little Bennett	0.8	0	1.0	79	0	7.0	98	0	–	–	–
Rachel Carson	2.0	33	4.5	68	0	–	–	–	–	–	–
Blockhouse Point	0.1	0	3.8	84	10	–	–	–	–	–	–
Black Hill	0.1	0	5.2	57	0	13.5	82	0	–	–	–
BARC	1.2	5	3.5	68	6	19.8	83	0	11.8	93	0
1990											
Little Bennett	1.0	0	0.5	*	0	5.0	85	0	–	–	–
Rachel Carson	–	–	–	–	–	31.5	76	0	–	–	–
Blockhouse Point	0.5	0	–	–	–	14.8	80	0	–	–	–
BARC	1.0	16	0.5	64	19	7.8	81	6	13.2	87	10
1991											
Wye Island	–	–	7.8	78	0	14.2	82	20	–	–	–
Seth Demo Forest	–	–	2.0	87	3	–	–	–	–	–	–
Linkwood	–	–	–	–	–	49.2	95	29	–	–	–
BARC	0.5	0	1.2	*	0	4.0	*	0	–	–	–
Mean	0.9	5.4	3.5	71.4	3.5	16.0	84.3	5.0	12.5	90.0	5.0

A dash (–) indicates that the treatment was not included at the specified location.
An asterisk (*) indicates that the data are not available.

Problem Identification. The evaluation of the specialized management program provided an opportunity to identify a number of limitations in the program that can be addressed both experimentally and operationally. For instance, some defoliation at BARC in 1990 occurred in an untreated area where the egg mass density was 1000/ha and the populations were declining. Ground observations indicated that most of that defoliation occurred in an area that had not been sampled using the 300-m grid scheme and that contained large numbers of preferred host trees. In forested areas, the amount of defoliation experienced in this untreated area at BARC probably would not be significant, but where high-value trees in an urban park setting are involved, a modified sampling scheme may be necessary to increase the probability of locating clumped gypsy moth populations. Further, in assessing the defoliation where diflubenzuron was used at BARC in 1990, most of the defoliation was found to be near a water tower and around the edges of the treated block. Therefore, there was strong circumstantial evidence that lack of desired spray deposition may have been a major problem. This reasoning is further supported by the extremely low population and the decrease in egg mass numbers measured in the centers of the two diflubenzuron spray blocks (Table 3). Also, regularly spaced, narrow bands of defoliation in a rather large spray block in the Seth Demonstration Forest in 1991 were obvious on the sketch map (Fig. 1). The characteristic "tiger stripes" parallel to the flight path are good indicators of skips in coverage between spray swaths.

Research Needs and Operational Improvements. The highest priority research needs and operational improvements associated with the specialized gypsy moth management program are related to sampling, improved spray coverage, and quantitative population dynamics associated with the relationships between egg mass numbers and size and subsequent larval numbers and defoliation. The 300-m grid sampling scheme did not, in at least one case, detect a high density clump of egg masses. In this case, the egg masses were associated with a group of preferred hosts. A modified sampling plan based on a detailed host survey may be necessary to increase the probability of preventing defoliation in areas where gypsy moth populations are highly clumped.

Improved spray coverage may provide the best opportunity for increasing the efficacy of the specialized program. The evidence that there were "skips" between swaths and inadequate coverage around the edges of spray blocks indicates that some improvements in aircraft guidance are needed. The use of electronic guidance systems (Souto 1991) or the actual marking of individual spray swaths may be necessary to further improve coverage. Occasionally, conditions exist which make skips in coverage unavoidable, such as when obstructions such as water and radio towers or other similar obstacles occur within spray blocks. In these situations, ground application may be the only alternative for increasing efficacy. Perhaps most important is the precise measurement of spray droplet characteristics and distributions in order to distinguish between failures caused by improper coverage and failures resulting from insufficient biological effectiveness. Applications of methods such as those developed by Bryant and Yendol (1991) should be very helpful in this regard.

Even when high levels of early larval mortality (95%) were obtained with two applications of *B. thuringiensis,* substantial defoliation occurred where high

Fig. 1. Areas of defoliation following one application of *Bacillus thuringiensis* in a gypsy moth management program on the Seth Demonstration Forest, Talbot County, MD, 1991.

density populations were present. In light of this evidence, there is a need to better understand the relationship between absolute larval numbers and defoliation so that prevention of defoliation can be more precisely predicted. A potentially useful method for estimating larval populations by collecting frass is available (Liebhold and Elkinton 1988) to assist in addressing this issue.

An alternative strategy that would involve treatment of gypsy moth populations at low levels, a year or two before they are expected to increase to high levels, should be considered (Ticehurst and Finley 1988). In the long term, this strategy may be necessary in order to prevent defoliation in areas where extremely high density populations may develop. Also, treatment thresholds lower than those adequate to prevent defoliation may be needed in residential and park settings to prevent the occurrence of nuisance problems associated with the presence of gypsy moth larvae. Because the identification of potential problem areas prior to an upturn in the infestation is very difficult, such approaches could be very costly, but the economics of gypsy moth management has not yet been critically examined.

In the short term, our research will be designed to address spray droplet distribution and to quantify larval populations in relation to defoliation. Such efforts should lead to some improvements in the specialized program and to better definition of those conditions where the specialized program as now designed may not realistically be expected to achieve the goal of preventing noticeable defoliation.

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