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Effectiveness of gypsy moth mating disruption from aerial applications of plastic laminate flakes with and without a sticking agent

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Abstract

1 The plastic laminate flake formulation, Disparlure II, is currently the only gypsy moth mating disruption product available for aerial application. The elimination of a sticking agent from the formulation would reduce costs, simplify application, and make it possible to apply the product without specialized equipment.

2 A test was conducted in wooded plots in Virginia during 1997 and 1998 to determine whether a sticking agent is necessary. Treatment effectiveness was assessed from the rates of male moth capture in pheromone-baited traps and mating success of both laboratory-reared and wild females.

3 Male moth capture was reduced 75.6 and 92.9% in plots treated with flakes without and with a sticking agent, respectively. The percentage of mated females that produced egg masses with more than 5% fertile eggs was reduced by 86.3 and 99.5% in plots treated with flakes without and with a sticking agent, respectively.

4 Moth capture and mating success of laboratory-reared females did not differ significantly between plots treated with flakes with and without a sticking agent. However, the consistently greater reduction in mating success in both years provides strong evidence that mating disruption is less effective when flakes are applied without a sticking agent. The proportion of wild egg masses collected in 1998 with more than 5% fertile eggs was significantly higher under the no-sticking agent treatment.

5 In special situations where the use of a sticking agent may be problematic, such as in residential areas, the data indicate that a high level of mating disruption is likely to occur even without the use of a sticking agent.

Keywords Aerial application, disparlure, forest pest, gypsy moth, laminate flakes, *Lymantria dispar*, mating disruption, pheromone.

Introduction

The gypsy moth *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae) is a serious pest and frequent defoliator of deciduous trees. Aerial applications of insecticides are often used to reduce impacts to forests and residential areas (USDA, 1995). Because of concern over potential undesirable effects of insecticides on non-target organisms, there is increasing interest in the use of gypsy moth-specific control tactics. One such tactic is the application of synthetic female gypsy moth sex pheromone (*Z*)-7,8-epoxy-2-methyloctadecane, or disparlure (Bierl *et al*., 1970), to disrupt mating and thereby reduce or eliminate subsequent populations. Multi-year studies have demonstrated that gypsy moth mating can be disrupted, and subsequent populations reduced, by aerial applications of disparlure in a plastic laminate flake formulation. Disruption of mating probably results from desensitization of male chemoreceptors and disorientation of male moths within pheromone-treated areas (Carde & Minks, 1995). Leonhardt *et al*. (1996) demonstrated that a single aerial application of 150 g/ha of racemic disparlure suppressed gypsy moth populations for three

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subsequent years compared to untreated controls, and Thorpe *et al*. (1998) reported population suppression in the year following an aerial application of flakes at a rate of 75 g/ha of disparlure. Earlier gypsy moth mating disruption research and development efforts are reviewed by Doane & McManus (1981) and Kolodny-Hirsch & Schwalbe (1990).

Currently, a plastic laminate flake formulation, Disrupt II, is the only gypsy moth mating disruption product that is registered with the United States Environmental Protection Agency and that is commercially available (Reardon *et al*., 1998). It consists of multilayered plastic flakes composed of an inner permeable layer containing disparlure sandwiched between outer polymeric layers. The flakes release approximately 30–40% of their disparlure content within 42 days after application (Reardon *et al*., 1998). Operationally, flakes are typically applied at a rate of 75 g a.i./ha based on the results of dose response studies conducted with ground-applied (Schwalbe & Mastro, 1988; Webb *et al*., 1990) and aerially-applied (Schwalbe *et al*., 1983; Webb *et al*., 1988) disparlure. The effectiveness of gypsy moth mating disruption decreases with increasing gypsy moth population density (Schwalbe *et al*., 1979, 1983; Webb *et al*., 1988; Kolodny-Hirsch *et al*., 1990), and there is evidence that the tactic is effective only when moth populations are sparse (Reardon *et al*., 1998).

As a result of gypsy moth mating disruption tests using hand-applied pheromone dispensers positioned at 1.5 m above the ground, Kolodny-Hirsch *et al*. (1990) and Kolodny-Hirsch & Webb (1993) found that mating success in sentinel females was greater at a height of 15–20 m than at 1.5 m. Based on these results, it was concluded that pheromone dispensers must be distributed throughout the forest canopy for mating to be disrupted at all heights. This led to the development of equipment suitable for the aerial application of flakes with a sticking agent (sticker) (Reardon *et al*., 1998). Special pods mounted on each wing of the aircraft mix flakes and sticker just before dispersal through a spinner. Leonard *et al*. (1992) found that, using this system in an operational application of flakes with an effective sticker, approximately 25% of the applied flakes were deposited in the upper canopy, 28% in the middle canopy, 25% in the lower canopy, 12% on understory vegetation, and 10% on the ground.

The use of a sticking agent in aerial flake applications increases costs, requires specialized equipment, and sometimes results in application problems such as clogs and loss of proper calibration. There are also situations in which it might be desirable to apply flakes without sticker, such as over residential areas. Furthermore, no data are available on the effectiveness of gypsy moth mating disruption in the canopy after an application of flakes to the forest floor, such as would occur if flakes were applied without sticker. Studies of the vertical profile of disparlure after an aerial application to forest canopies (Plimmer *et al*., 1978; Caro *et al*., 1981) indicate that the vertical distribution of disparlure follows the vertical distribution of the dispensers. This suggests that, when flakes are applied without sticker and mostly fall to the ground, there should be a lower concentration of disparlure in the canopy than when sticker is used. However, this has not been tested experimentally, nor has the effect of the distribution of aerially applied dispensers on the effectiveness of mating disruption been investigated.

This paper reports the results of a 2-year (1997–98) cooperative USDA study to compare the ability of aerial applications of Disrupt II flakes with and without sticker to disrupt gypsy moth mating. This work is a continuation of efforts to reduce the cost and increase the effectiveness of gypsy moth mating disruption (Reardon *et al*., 1998).

Methods

Plot description

The test plots in 1997 were 12 isolated woodlots (20–69 ha) located in central Virginia in the mid-Atlantic region of the United States. In 1998, 12 test plots (100 ha) were delineated within continuously forested areas in the same general area. A randomized block design with four blocks of each of the three treatments was used both years. Sampling was conducted within 8.1 ha core areas in the centre of each plot. Tree basal area within the core areas of each plot was estimated from five variable-radius survey points using a BAF-5 prism (Wilson & Fontaine, 1978). Maximum canopy height was measured at each point with a clinometer. The average oak basal area, non-oak basal area, and canopy height for the plots used in 1997 and 1998 are given in Table 1. The predominant overstory oaks were white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), red oak (*Q. rubra* L.), black oak (*Q. velutina* Lamark) and scarlet oak (*Q. coccinea* Muenchhausen). The predominant overstory non-oak tree species were hickory (*Carya* spp.), black gum (*Nyssa sylvatica* Marshall), tulip tree (*Liriodendron tulipifera* L.), white pine (*Pinus strobus* L.) and Virginia pine (*P. virginiana* Miller). The understory was predominantly blueberry (*Vaccinium* spp.), mountain laurel (*Kalmia latifolia* L.) and flowering dogwood (*Cornus florida* L.). Five egg mass surveys were conducted within the core sampling area of each plot (Liebhold *et al*., 1994), but no more than one new egg mass was found in any of the plots. Burlap bands (25 cm wide) were placed at a height of 1.4 m around the boles of 100 oak trees within the core sampling area of each plot. The number of gypsy moth pupae under these bands at the end of larval development is given in Table 1. As pupal numbers are not affected by mating disruption treatments, these values provide a relative estimate of pretreatment gypsy moth population density in these plots (Wallner *et al*., 1989). Population density was lower in 1997 than in 1998, but was very low both years (< 1 larva per tree, according to the regression equation in Wallner *et al*. (1989; equation 6) relating number of larvae under burlap to the total number of larvae in a tree).

Table 1 Tree basal area, canopy height and number of gypsy moth pupae, Virginia 1997 and 1998.

Year	Oak basal area (m^2/ha)	Non-oak basal area (m^2/ha)	Maximum canopy height (m)	Pupae/100 burlap bands
1997	14.5 ± 1.1	10.8 ± 1.0	30.4 ± 1.0	2.1 ± 0.2
1998	14.9 ± 0.5	7.0 ± 1.0	26.0 ± 0.9	11.8 ± 4.0

Values are mean ± SEM.

Treatments

Separate tests were conducted in 1997 and 1998. Each test consisted of the following treatments: flakes with sticker, flakes without sticker, and an untreated control. The flakes (Disrupt II, Hercon Environmental, Emigsville, PA, U.S.A.) were applied at a dose of 75 g a.i./ha. The flakes (1 × 3 mm) had 3 ml polyvinyl chloride (PVC) outer layers and an inner polymer layer containing racemic disparlure (18.5% a.i.). The flakes and 3% (w:w) diatomaceous earth (to reduce clogging) were applied with 280 g/ha of a sticker (Gelva 2333, Solutia Inc., Springfield, MA, U.S.A.) or without sticker. Gelva 2333 is a multipolymer emulsion used industrially primarily as a pressure-sensitive adhesive. In 1997, applications were made on 30 June with a Cessna 206 fixed-wing aircraft flying 8–15 m above the canopy at a speed of 185 km/h and with a lane separation of 15 m. In 1998, applications were made on 18 and 19 June with an Air Tractor fixed-wing aircraft flying 8–15 m above the canopy at a speed of 225 km/h and with a lane separation of 23 m. Specialized application pods (Schweitzer Aircraft Corp., Elmira, NY, U.S.A.) were used to mix and dispense the flakes and sticker. The rate of pheromone release from the applied flakes was not determined in this study. However, in previous studies where the Disrupt II flakes were applied under similar conditions, the flakes released 30–50% of their disparlure content over the 6-week period of male moth flight (Leonhardt *et al*., 1996; Thorpe *et al*., 1998).

Efficacy assessment

Biological efficacy was assessed by measuring the effects of the treatments on the capture of male moths and on female mating success. To sample in the canopy, pulley systems were constructed by pulling a nylon string attached to a metal ring over a branch in the upper canopy of an overstory tree at each of 15 (1997) or 10 (1998) points within the core sampling area of each plot. Additional nylon string was threaded through this metal ring and two additional rings each fastened 1.5 m above ground level and positioned so that the string formed a triangular loop which could slide through the rings. Traps containing either lures or monitor females were then attached to the string so that they could be pulled into the canopy. The pulley systems were separated by a minimum distance of 50 m. At each of five pulley systems in each plot, a standard USDA milk carton trap containing a plastic laminate dispenser loaded with 500 µg of (+)-disparlure was placed at 1.5 m and in the canopy at the top of the pulley system. In 1997, traps were deployed at 2–5 d intervals from 7 July to 9 September. In 1998, traps were deployed every other day from 10 July to 2 August. Gypsy moths were counted in each trap at the end of each deployment period. Trap data from the year of the treatment were interpreted to indicate the effects of the treatments on the ability of males to locate and enter traps. A reduction in male moth capture indicates that the treatment interfered with normal gypsy moth chemical communication.

Laboratory-reared virgin females were placed in each plot to determine the effects of the treatments on mating success. Previous field evaluations have confirmed that the attractiveness of laboratory-reared females to wild males does not differ from that of wild females (V.C. Mastro, unpublished results). A one-day-old virgin female was placed at each of 15 (1997) or 10 (1998) pulley systems in each plot at heights of 1.5 m and in the canopy. Females were placed untethered on pieces of burlap fastened inside triangular cardboard mating stations (Delta traps). In 1997, females were placed at 2–5 d intervals from 7 July to 12 September. In 1998, females were placed every other day from 10 July to 2 August. Females were retrieved 24 h later and placed, along with any eggs that had been deposited, in a small paper bag in an outdoor insectary. After a minimum of 30 days, all eggs were examined for embryonation. Females producing egg masses that contained at least one embryonated egg were considered to be mated and those producing only unembryonated eggs were considered to be unmated. The number of embryonated and unembryonated eggs in each egg mass was recorded. At the completion of oviposition by wild gypsy moths, all egg masses found beneath burlap bands were collected, held under ambient conditions for at least 30 days, and then inspected for embryonation.

In 1997, the study area had very low gypsy moth populations. To ensure that male moth density was adequate to measure efficacy, laboratory-reared male moths were released at a target rate of 150 males per plot every 3 days for the 9-week evaluation period. To distinguish them from feral males after capture in pheromone traps, laboratory-reared pupae were dusted with a fluorescent powder which was transferred to male moths as they eclosed. The proportion of released males averaged 76% during the evaluation period.

Data analysis

Male trap catch and egg mass data from laboratory-reared females were analysed by a mixed-model analysis of variance (ANOVA) (SAS, 1996; Proc Mixed). Data from each year were analysed separately. For each dependent variable, deviations from the assumption of variance homogeneity were detected by calculating the Spearman's correlation between the predicted values and the absolute values of the residuals (the actual minus the predicted response). When a significant correlation occurred, a logarithmic transformation of the form $Y_{transformed} = \log (Y + \text{constant})$ was performed (Berry, 1987). For each analysis, a constant resulting in the most homogeneous variance was used for the transformation (Carrol & Ruppert, 1988). Pre-planned orthogonal comparisons of the control vs. the two Disrupt II treatments and of the Disrupt II formulation applied with and without sticker were performed. Untransformed values and standard errors are reported in the tables. Chi-square tests (SAS, 1996; Proc Freq) were used to detect differences among the treatments for egg masses collected from wild females.

Results

Male moth catch

The male moth trap data are shown in Tables 2 and 3. The treatment effect was significant for 1997 ($F = 35.1$; d.f. = 2,15; $P < 0.0001$) and 1998 ($F = 10.0$; d.f. = 2,15; $P = 0.002$) (Table 4). The sticker and no sticker treatments were not significantly different from each other in either year, but both treatments had values that were significantly lower than those of the control. The

Table 2 Gypsy moth male trap capture and egg mass embryonation rates in plots treated with Disrupt 11 flakes with or without sticker, Virginia 1997.

Treatment	Height	No. males/trap/day[a]	Percent embryonated egg masses[b]	Percent of embryonated egg masses with > 5% fertile eggs[a]	Percent of egg masses with > 5% fertile eggs[a]
Control	Canopy	0.10 ± 0.05	3.8 ± 1.1	55.0 ± 18.7	2.5 ± 1.2
	Ground	0.40 ± 0.15	14.6 ± 3.2	82.3 ± 2.0	12.2 ± 2.9
No sticker	Canopy	0.01 ± 0.007	1.3 ± 0.4	31.3 ± 23.7	0.3 ± 0.2
	Ground	0.03 ± 0.015	2.3 ± 0.7	20.8 ± 12.5	0.7 ± 0.4
Sticker	Canopy	0.0006 ± 0.0006	1.4 ± 0.4	25.0 ± 25.0	0.1 ± 0.1
	Ground	0.002 ± 0.002	1.4 ± 0.3	0	0

Values are mean ± SEM for four replicate plots.
[a]Means for the sticker and no-sticker treatments are not significantly different, but both are significantly lower than the control mean (pre-planned orthogonal contrasts).
[b]Comparisons among the treatment means were not performed because the treatment–height interaction effect was significant.

Table 3 Gypsy moth male trap capture and egg mass embryonation rates in plots treated with Disrupt II flakes with or without sticker, Virginia 1998.

Treatment	Height	No. males/ trap/day[a]	Percent embryonated egg masses[a]	Percent of embryonated egg masses with > 5% fertile eggs[a]	Percent of egg masses with > 5% fertile eggs[a]
Control	Canopy	0.50 ± 0.21	5.3 ± 1.5	23.1 ± 10.3	1.7 ± 1.0
	Ground	1.09 ± 0.32	6.1 ± 1.7	52.1 ± 18.8	4.0 ± 1.9
No sticker	Canopy	0.27 ± 0.16	3.9 ± 1.2	19.0 ± 11.2	1.0 ± 0.7
	Ground	0.38 ± 0.29	2.3 ± 0.8	8.3 ± 8.3	0.2 ± 0.2
Sticker	Canopy	0.12 ± 0.12	2.0 ± 0.9	0	0
	Ground	0.10 ± 0.08	2.0 ± 0.6	0	0

Values are mean ± SEM for four replicate plots.
[a]Means for the sticker and no-sticker treatments are not significantly different, but both are significantly lower than the control mean (pre-planned orthogonal contrasts).

Table 4 Results of analysis of variance of the effects of treatment and height on gypsy moth male trap capture and egg mass embryonation rates, Virginia 1997 and 1998.

			No. males/trap/day		Percent embryonated egg masses		Percent of embryonated egg masses with > 5% fertile eggs		Percent of egg masses with > 5% fertile eggs	
Year	Source	d.f.	*F*	P	F	P	F	P	F	P
1997	Treatment	2	35.1	< 0.0001	23.5	< 0.0001	6.1	0.01	18.7	< 0.0001
	Height	1	7.8	0.01	9.2	0.008	0.04	0.85	2.4	0.14
	Trt. × Hgt.	2	3.5	0.06	4.6	0.03	1.3	0.30	2.8	0.09
1998	Treatment	2	10.0	0.002	6.8	0.008	9.9	0.002	10.2	0.002
	Height	1	3.2	0.10	0.1	0.75	0.04	0.85	0.1	0.72
	Trt. × Hgt.	2	2.1	0.16	0.7	0.51	0.8	0.48	1.8	0.21

effect of vertical position was significant in 1997 ($F = 7.8$; d.f. = 1,15; $P = 0.01$), with greater trap catch at the lower level, but not in 1998 ($F = 3.2$; d.f. = 1,15; $P = 0.10$). The treatment by position interaction effect was not significant in 1997 ($F = 3.5$; d.f. = 2,15; $P = 0.06$) or 1998 ($F = 2.1$; d.f. = 2,15; $P = 0.16$).

Female mating success

The percent of females mated, as determined by the presence of one or more fertile eggs, is shown in Tables 2 and 3. According to the ANOVA, the treatment effect was significant in 1997 ($F = 23.5$; d.f. = 2,15; $P < 0.0001$) and 1998 ($F = 6.8$; d.f. = 2,15; $P = 0.008$) (Table 4). The height effect was significant in 1997 ($F = 9.2$; d.f. = 1,15; $P < 0.008$), but not in 1998 ($F = 0.1$; d.f. = 1,15; $P = 0.75$). The treatment by height interaction effect was significant in 1997 ($F = 4.6$; d.f. = 2,15; $P = 0.03$), apparently because the effect of height on mating success was greatest in the absence of a mating disruption treatment. This interaction effect was not significant in 1998 ($F = 0.7$; d.f. = 2,15; $P = 0.51$). The percentage of females that were mated in the control plots averaged 14.6 at ground level and 3.8 in the canopy in 1997, and 6.1 at ground level and 5.3 in the canopy in 1998. In plots treated

with mating disruptant without sticker, these values were 2.3 and 1.3% in 1997 and 2.3 and 3.9% in 1998 for the ground and canopy placements, respectively. With sticker, these values were 1.4% at both the ground and canopy level in 1997, and 2.0% at both the ground and canopy level in 1998. The values from the sticker and no sticker treatments were not significantly different in either year, but both were significantly lower than those from the corresponding controls.

The number of fertile eggs within an egg mass varied over a wide range, and was affected by the mating disruption treatments (Tables 2 and 3). In 1997, the percentages of egg masses with more than 5% fertile eggs were 0 and 25.0% in plots treated with flakes with sticker, 20.8 and 31.3% in plots treated with flakes without sticker, and 82.3 and 55.0% in untreated plots at the ground and canopy levels, respectively. In 1998, these values were 0 and 0, 8.3 and 19.0, and 52.1 and 23.1% in plots treated with flakes with sticker, without sticker, and untreated, and at the ground and canopy levels, respectively. An ANOVA indicated that the treatment effects were significant in 1997 ($F = 6.1$; d.f. = 2,15; $P = 0.01$) and 1998 ($F = 9.9$; d.f. = 2,15; $P = 0.002$) (Table 4). The height effect ($F = 0.04$; d.f. = 1,15; $P = 0.8$ and $F = 0.04$; d.f. = 1,15; $P = 0.9$) and the treatment by height interaction effect ($F = 1.3$; d.f. = 2,15; $P = 0.3$ and $F = 0.08$; d.f. = 2,15; $P = 0.5$) were non-significant for 1997 and 1998, respectively. The values from the plots treated with flakes with sticker were not significantly different from those from plots treated with flakes without sticker in either year, but the values from the treated plots were significantly lower than those from the corresponding untreated plots.

Because the contribution to the next generation of any egg mass with less than 5% fertile eggs is insignificant, the effect of the treatments on mating success was recalculated after redefining a female as successfully mated only if she produced an egg mass with greater than 5% fertile eggs. These values are shown in the last column of Tables 2 and 3. In 1997, mating success based on this new definition was reduced to 12.2 and 2.5% in the control plots, 0.7 and 0.3% in the plots treated with flakes with no sticker, and 0 and 0.1% in plots with sticker, for the ground and canopy positions, respectively. The treatment effect was significant ($F = 18.7$; d.f. = 2,15; $P < 0.0001$; Table 4). The height and treatment by height interaction effects were not significant ($F = 2.4$; d.f. = 1,15; $P = 0.1$ and $F = 2.8$; d.f. = 2,15; $P = 0.1$, respectively). The values from the with and without sticker treatments were not significantly different from each other, but both were significantly lower than those from the controls. In 1998, mating success based on the new definition was reduced to 4.0 and 1.7% in the control plots, 0.2 and 1.0% in the plots treated with flakes with no sticker, and 0 and 0% in plots with sticker, for the ground and canopy positions, respectively. The treatment effect was significant ($F = 10.2$; d.f. = 2,15; $P = 0.002$). The height and treatment by height interaction effects were not significant ($F = 0.1$; d.f. = 1,15; $P = 0.7$ and $F = 1.8$; d.f. = 2,15; $P = 0.2$, respectively). The values from the with and without sticker treatments were not significantly different from each other, but both were significantly lower than those from the controls. These adjusted values correspond to reductions in mating success of 93.6 and 79.0% for flakes without sticker and 99.0 and 100% for flakes with sticker in 1997 and 1998, respectively.

Table 5 Embryonation rates of egg masses from wild gypsy moths collected from plots treated with Disrupt II flakes with or without sticker, Virginia 1998.

Treatment	No.of egg masses collected	Percent embryonated egg masses	Percent of embryonated egg masses with > 5% fertile eggs	Percent of egg masses with > 5% fertile eggs
Control	6	100a	100a	100a
No sticker	20	55b	100a	55b
Sticker	34	5.9c	50b	2.9c

Percentages within a column followed by different letters are significantly different (χ^2 test, $P < 0.0001$).

Mating success of wild females

In 1997, no egg masses were deposited beneath burlap bands by wild females. In 1998, a total of 60 egg masses that had been deposited by wild females was collected within the treated and control plots (Table 5). Six egg masses were collected from beneath burlap bands in untreated plots. All six of these egg masses contained more than 5% embryonated eggs. Of the 20 egg masses collected from plots treated with flakes without sticker, 55% contained embryonated eggs, and in each of these more than 5% of the eggs were fertile. Of the 34 egg masses collected from plots treated with flakes with sticker, only 5.9% contained any embryonated eggs. Fifty percent of these egg masses contained more than 5% fertile eggs. This corresponds to reductions in mating success, defined as egg masses with more than 5% fertile eggs, of 45.0 and 97.9% for flakes without and with sticker, respectively.

Discussion

Richerson *et al*. (1976) found that virgin female gypsy moths that had laid more than one unfertilized egg prior to exposure to males were less likely to produce fertile eggs after mating. Under low moth density conditions, mating was reduced among these females. Mating was not reduced under high density conditions, yet these females also produced few fertile egg masses. The number of fertile eggs within a mass was not reported in this paper. Mating disruption treatments probably delay mating, which probably leads to a higher incidence of the release of unfertilized eggs by virgin females. This may explain the higher proportion of mated females in the treated plots in the current study with < 5% fertile eggs.

During mating disruption tests in Maryland in 1975 and 1977, Webb *et al*. (1981) noted a discrepancy between determinations of mating success based on the presence of sperm in the bursa copulatrix (Stark *et al*., 1974) vs. the presence of embryonated eggs, and described a 'sterility factor'. In these tests, mating was reduced by the mating disruption treatments from 51 to 76% based on the presence of sperm, and from 81 to 99% based on the presence of embryonated eggs in the egg mass. Although the mechanism responsible for this effect is not known, Webb *et al*. (1981) speculated that high temperatures and/or the use of laboratory-reared females may have played a role. The cause of the sterility factor effect reported by Webb *et al*. (1981) may also

be responsible for the higher incidence of sparsely embryonated egg masses in treated plots found in both years of our study.

The higher embryonation rate of wild egg masses compared to egg masses produced by laboratory-reared virgin females is probably due to a combination of factors, including a longer exposure period for wild females and a location (tree boles) which is more likely to be searched by males (Richerson *et al*., 1976; Carde & Hagaman, 1984). The laboratory-reared females were inside Delta traps, which may have reduced encounter rates with males. The no-sticker treatment appeared to be less effective when egg masses produced by wild females were considered (45% reduction in egg masses with > 5% fertile eggs) than when egg masses produced by laboratory-reared females were considered (93% and 79% reductions in 1997 and 1998, respectively). This may be an artefact related to the small sample size of the egg masses produced by wild females, or it could be that the use of laboratory-reared females underestimated mating success under the no-sticker treatment.

The use of sticker did not result in a significant difference in either male moth catch or mating success of laboratory-reared females in either of the 2 years of our study. However, the application of flakes with sticker consistently resulted in greater reductions in moth catch and mating success, and increases in the incidence of unembryonated eggs produced by mated females, suggesting that the application of flakes with sticker is more effective than without sticker. This trend is further supported by data from egg masses produced by wild females. Therefore, the results of this study indicate that, to achieve maximum efficacy with Disrupt II, a sticker should be used. On the other hand, in special situations where the use of sticker is problematic, such as in residential areas, the data indicate that a high level of mating disruption can be expected to occur with the application of Disrupt II flakes without sticker.

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