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DISRUPTION OF SPRUCE BUDWORM MATING BY MEANS OF HERCON PLASTIC LAMINATED FLAKES, ONTARIO 1981

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ABSTRACT

A high dose of synthetic sex pheromone of the spruce budworm (*Choristoneura fumiferana* [Clem.]) (100 gai/ha) formulated in Hercon flakes was applied by aircraft to a 30 ha white spruce (*Picea glauca* [Moench] Voss) plantation near Sault Ste. Marie, Ontario, in 1981. Mating among caged moths was reduced by 40%, and catches in pheromone-baited traps were reduced by 90%. Effects on moth behavior and on population reduction were obscured by a widespread population collapse but the available data suggest that there was a delay in oviposition, although final egg counts were the same in treated and check plots. Chemical analysis of the flakes indicated that release rates were satisfactory, but comparison between counts of flakes deposited on drop sheets and on foliage suggested that flakes did not adhere well on impact. It is concluded that more work is required in the laboratory and in small-scale field experiments to evaluate 'stickers' and to determine the optimum concentration and distribution of formulations before further extensive field trials are carried out.

RÉSUMÉ

En 1981, on a appliqué par avion, à raison de 100 grains d'ingrédient actif par hectare, une forte dose d'une phéromone sexuelle de synthèse de la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* [Clem.]), incorporée dans des paillettes Hercon, sur une plantation de 30 ha d'épinette blanche (*Picea glauca* [Moench] Voss) située près de Sault Ste-Marie en Ontario. L'accouplement de papillons gardés dans des cages a été réduit de 40%, et le nombre de captures dans les pièges à phéromone a été réduit de 90%. Les effets du traitement sur le comportement des papillons et sur la population de tordeuses ont été masqués par un effondrement général de la population, mais d'après les données en main, il y aurait eu un retard dans la ponte, même si le nombre d'oeufs a finalement été le même dans la parcelle traitée et la parcelle témoin. D'après l'analyse chimique des paillettes, le rythme de libération de l'attractif était satisfaisant, mais d'après le nombre de paillettes retrouvé au sol et le nombre retrouvé dans le feuillage, les paillettes adhèrent mal au moment de l'impact. On conclut qu'il faut poursuivre les expériences en laboratoire et à petite échelle pour évaluer des préparations de colles et déterminer la concentration et la distribution optimales de ces préparations avant d'entreprendre d'autres essais d'envergure sur le terrain.

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INTRODUCTION

Previous tests of the aerial application of synthetic sex attractant of the spruce budworm (*Choristoneura fumiferana* [Clem.]) resulted in reductions of up to 90% of males captured in traps baited with virgin females and/or synthetic lures. However, there has been no convincing demonstration of a reduction in population density in the subsequent generation.

In 1975 microcapsules were applied to 12 ha (7.4 gai/ha)[1] in Ontario with 97% reduction in catches (Sanders 1976). In 1977, again in Ontario, Conrel hollow fibres containing the synthetic attractant were applied at a rate of approximately 30 and 3 gai/ha to two 10 ha plots in low-density populations and at approximately 5 gai/ha to a moderate density population (Sanders 1979). In all three areas the reduction in catches was greater than 97%, but attempts to demonstrate population reduction were inconclusive. In 1978 four different concentrations ranging from 0.2 to 40 gai/ha were applied in New Brunswick and Nova Scotia (Miller 1980). Unfortunately, the active ingredient evaporated too quickly from the Conrel fibres and was largely gone by the peak of the moth flight season, an indication of shortcomings in the formulation (Wiesner *et al.* 1980). In spite of this, during the period when the attractant was present in the air space, catches in traps were considerably reduced. Also, in cages containing different numbers of male and female budworm, there were significant reductions in the numbers of females mated in the presence of the attractant, with the effects being greatest at the lowest population densities (Schmidt *et al.* 1980). Following the 1978 trial Canadian Forestry Service (CFS) personnel decided not to conduct any further trials until a suitable formulation had been adequately tested under field conditions. In 1980 one of the most promising of the available formulations was evaluated by the New Brunswick Research and Productivity Council (RPC), with CFS funding, during a field trial of the sex pheromone conducted in Maine, with State of Maine and Canada-United States Spruce Budworms Program (CANUSA) funding. The formulation, Hercon flakes, performed satisfactorily: the attractant was emitted as called for in the specifications. However, even though one treatment consisted of a massive dose of attractant (500 gai/ha), there were no clearcut effects on the subsequent generation (J.B. Dimond, Univ. Maine, Orono, pers. comm.). Possibly invasion of gravid females confounded the results. It is also possible that the high density of the population resulted in a sufficiently high incidence of chance encounters leading to mating, which masked the effect of the treatment.

Experiments with a wind tunnel to assess the effects of different pheromone concentrations on mating disruption suggest that atmospheric concentration has to be at least 0.1 μg/m^3 before there is any disruption (Sanders 1982). The results of the 1980 experiment in Maine show that 500 gai/ha in Hercon flakes gave an atmospheric concentration during the critical period of between 1 and 2 μg/m^3 (Silk, unpublished data). Therefore, an application rate of 100

[1]gai = grams of active ingredient

gai/ha of the same formulation should provide an atmospheric concentration above the required threshold.

A small-scale field experiment involving the Hercon flake formulation was therefore carried out in Ontario in 1981. The objective was to integrate population sampling and observations on moth behavior in an attempt to explain the mode of action of the disruption process and where it was deficient. The plan was to apply a relatively high dose of pheromone to a moderately high-density population and to observe and monitor the effects of the treatment on moth behavior:

- by observing and recording levels of male activity
- by measuring male orientation to lures and virgin females
- by observing and recording the incidence of female dispersal flight
- by collecting and dissecting females every few days to determine mating success
- by caging male and female moths and dissecting the females
- by carrying out frequent egg sampling to determine the effects on oviposition.

TREATMENT AREAS

The area chosen for treatment was a 30 ha white spruce (*Picea glauca* [Moench] Voss) plantation located about 16 km due north of Thessalon, Ontario. A similar plantation, 7.5 ha in size and 10 km to the southeast of the treated area, was selected as a check plot (Fig. 1). The trees in both plots were 45 years old and 15-18 m high. In each plot a scaffold 16.5 m high was erected with wooden planks at various heights to enable observations to be made of moth behavior in and above the tree crowns.

To facilitate sampling, the monitoring of weather conditions, and the deployment of cages and traps, lines were marked and cleared out at 100 m intervals through the treated plot. Two 5 x 6 grids with 20 m between lines were also marked out and cleared for the deployment of the baited sex pheromone traps. Since the check plot had been thinned and pruned previously, no clearing for access routes into the stand was necessary.

CHEMICAL FORMULATION AND APPLICATION

Formulation

Synthetic spruce budworm attractant, Δ-11-tetradecenal (TDAL) with an (E:Z) ratio of 95.6:4.4, was incorporated by the Hercon Division of Health-Chem Corp., New York, into square plastic flakes, each approximately 3 x 3 mm, at a concentration of 9.9% ai by weight.

Analysis was carried out by RPC, each flake being soaked overnight in toluene and then shaken with 3-4 ml n-hexane. Addition of the hexane flocculated the polymeric material. This material was filtered, the residue was washed with hexane and the washings were combined. The resultant extract, at an appropriate volume, was analyzed by gas chromatography on a Varian 3700 GC with FID detector. The column used was a 40 m SP1000

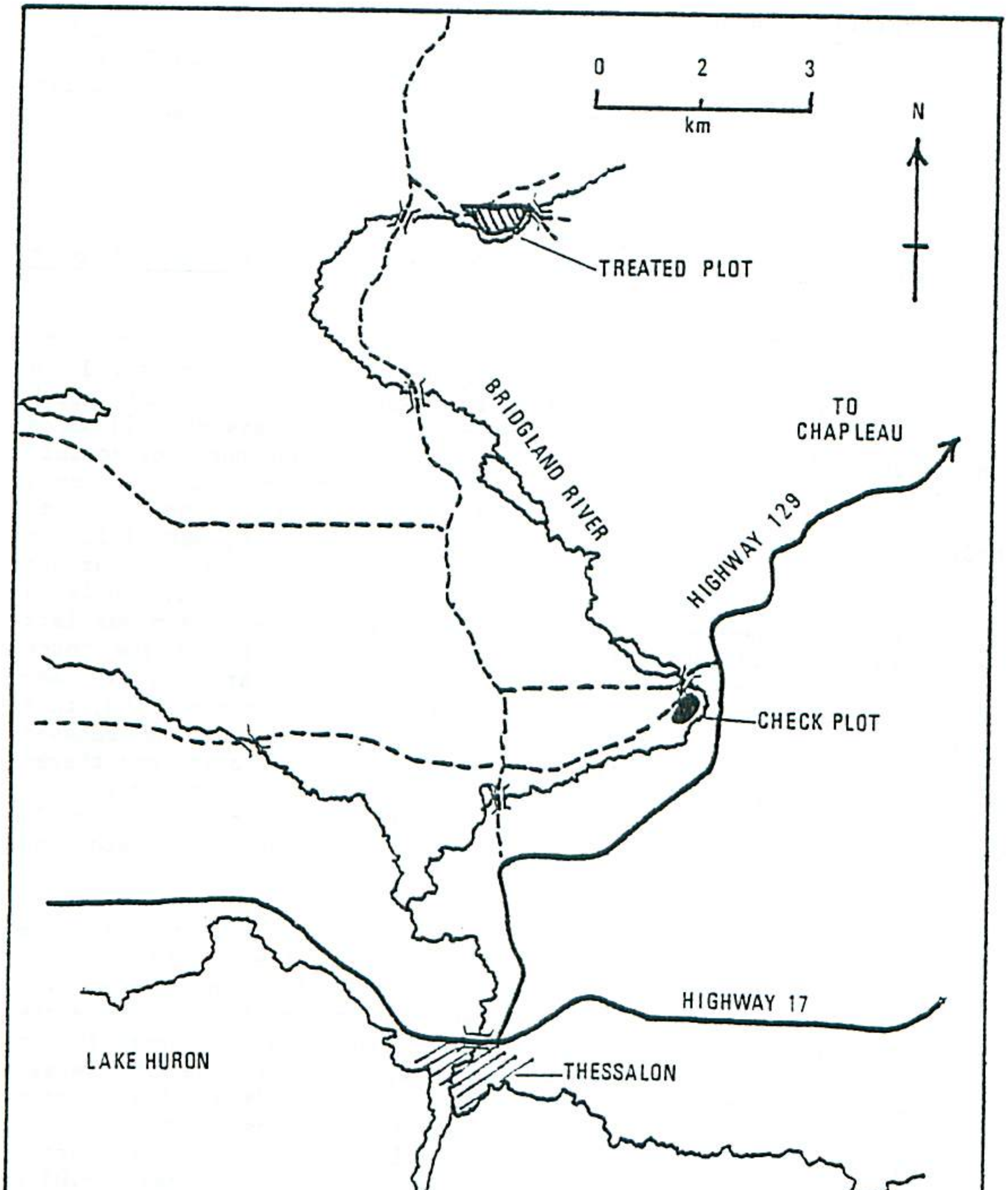

Figure 1. Map showing location of treated and check plots north of Thessalon, Ontario.

G-SCOT capillary operated isothermally at 170°C. A split-injection technique was applied and hydrogen was used as carrier gas at an inlet pressure of 5 kg/cm^2. This column gave baseline separation of E/Z isomers.

The analysis of 10 flakes collected prior to application gave the results shown in Table 1. Average content (± 1SD) was 9.63% ± 1.45 ai by weight or 690.5 μg/flake. Owing to variation in percent concentration and weight of flakes, the weight of attractant ranged from 491 to 983 μg/flake.

Application

The flakes were applied by a Piper Pawnee (Schweizer Aircraft Corp., Elmira, N.Y.) equipped with a custom-designed pod under each wing, which dispersed the flakes at a known rate and coated them with sticker as they were emitted. The sticker was a water emulsion of Grade 32 polybutene, containing 50-60% water.

The pods were ground calibrated to emit ca 1800 g of flakes (ca 250,000 flakes)/min., and ca 250 ml sticker/min.

The aircraft was flown at 144 km/hr at a height of about 16 m, each pass being 16 m apart. This gives a theoretical deposit of 6.5 flakes/m^2 per pass.

The formulation was applied on 25 and 26 June. One complete pass was made on the evening of 25 June. On the morning of 26 June two additional passes were made. However, on the first of these the applicator on one side of the aircraft was not functioning. The plot was therefore sprayed a total of two and a half times which, at a rate of 6.5 flakes/m^2 per pass, gives a theoretical deposit of 16.25 flakes/m^2.

Deposit

Counts of flakes on deposit sheets

Actual deposit at the time of application was measured in two ways. First, 20 cloth screens, each measuring 71 cm x 71 cm, were suspended horizontally in the tree canopies. Second, 10 black plastic sheets, each measuring 3 x 3 m, were laid out on the ground in clearings throughout the stand, while a larger strip 3 x 17.5 m was laid out across a road on the north side of the treated plot. Because of a misunderstanding, this last plastic sheet was removed before the final pass, and therefore recorded only one pass on 25 June and the first pass on 26 June when a single applicator was functioning.

Average deposit of the flakes on the cloth deposit screens in the canopy was 3.2/screen (range 0-9), and since each screen measured approximately 0.5 m^2 this gave an average deposit of 6.4/m^2. The average number of flakes on the 3 x 3 m plastic sheets on the forest floor was 41.4 (range 0-105). The actual area of each sheet was 9.3 m^2, which gave an estimated deposit rate of 4.5 flakes/m^2. On the large sheet a total of 359 flakes were counted. Since the area of this sheet was 53 m^2 this gave a deposit rate of 6.8 flakes/m^2 for 1 1/2 passes or

Table 1. Weight of 10 Hercon flakes collected prior to application showing percent active ingredient and actual weight of attractant.

	Weight of flake (mg)	Attractant (%)	Weight of attractant (μg)
1	8.15	6.48	528
2	6.95	8.38	582
3	7.15	10.78	771
4	6.45	8.46	546
5	9.15	10.74	983
6	7.80	10.54	822
7	6.85	10.84	743
8	8.60	10.36	891
9	4.75	10.34	491
10	5.85	9.37	548
Average	7.17	9.63 ($\pm$ 1.45 = 1SD)	690.5 ($\pm$ 174 = 1SD)

$11.3/m^2$ for 2 1/2 passes. Since the 3 x 3 m sheets on the ground were overhung partially by the canopy of the trees it is inevitable that some of the flakes would have hung up in the foliage above the sheets; the same is probably true, but to a lesser extent, for the deposit screens in the canopy. This would therefore explain the lower counts on the screens in the forest and a figure of 10 flakes/m^2 for the application is a reasonable estimate.

<u>Counts of flakes in trees, taken from a bucket truck</u>

Foliage was examined and flakes were counted from a 13 m bucket truck operating along a sand road running east-west through the plot. Counts could be made only on one side of each tree. In all, 38 flakes were counted on 17 trees (i.e., 2.24/ 1/2 tree or 4.5/tree), with a range of 0-7. These were distributed on the trees as follows: the top 3 m of the crown, 5; the next 3 m down, 15; the next 3 m, 9; and the remaining part of the crown, 9. The average surface area of each tree in plan view was conservatively estimated at 10 m^2 (a radius of 1.8 m for the longest branches) or 5 m^2 for half a tree, which gives a deposit of only 0.45 flakes/m^2. This compares very unfavorably with the deposit estimate of $10/m^2$ on the large drop sheet and implies that adhesion of the flakes to the trees was poor, with possibly only 5% of the flakes which impinged on the foliage actually adhering.

It may be argued that searching the foliage from a bucket truck for plastic flakes measuring 3 x 3 mm is not very efficient, and that many would have been missed. In reality the flakes, which were white, were extremely conspicuous, and it is unlikely that many were missed. Even if it is accepted that only 50% were found, the deposit rate on the foliage is still only 10% of what was expected. The conclusion, therefore, is that up to 95% of the flakes impinging on the tree crowns either passed straight through or bounced off. It is unfortunate that drop sheets were not placed under the trees to monitor the number of flakes reaching the ground. Certainly this should be included in any future evaluations.

Retention of flakes on trees

On 27 June, 500 of the same flakes as were used in the trial, coated in the emulsified polybutene sticker, were placed with forceps on branches and leaves of trees in the treated area as follows: 225 on spruce foliage, 175 on defoliated spruce branches, 50 on dead spruce branches, and 50 on hardwood leaves. Percentages of these flakes remaining after various intervals of time are shown in Table 2. Retention was poorer in the absence of needles, and this suggests that many flakes were held by the needles rather than by the sticker. This hypothesis is supported by the fact that there is poor retention on the flat surface of hardwood leaves, and by the observation that, after 32 days, flakes could be dislodged from among the needles by gentle shaking, the implication being that the sticker had evaporated.

The number of flakes dislodged from trees in the treated area was monitored by placing the ten 3 x 3 m plastic sheets under the tree crowns. On the 18th day after application six flakes were found, and a further six were found on day 40, for a total of 1.2/sheet or only $.13/m^2$--less than 2% of the original estimated deposit rate. However, if the numbers indicated by the examination with the bucket truck of the initial retention of 0.45 flakes/m^2 are accurate, then a loss of $.13/m^2$ (or 29%) becomes important.

Release Rates of Attractant in the Field

Release rates of the attractant were determined by measuring residual amounts of attractant in flakes collected from the field. A total of 20 flakes were taken at each sample date and were returned to the laboratory and stored at -11°C until the end of the experiment, when they were sent to RPC for analysis. Residual attractant was extracted and analyzed as described earlier; the results are shown in Table 3 and Figure 2. Approximately one third of the material had evaporated by day 4, one half by day 10 and two thirds by day 25. Since the formulation was designed to last 6 weeks, this demonstrates a satisfactorily efficient use of the material.

Atmospheric Concentration of Attractant

Concentrations of the attractant in the atmosphere were measured by passing air through a resin which adsorbed the attract-

Table 2. Percentage of flakes remaining on foliage and branches at various time intervals after placement on foliage by hand.

Location of flakes	n	Days after application				
		6	24	32	40	59
Spruce foliage	225	97	96	95	81	75
Partially foliated spruce	175	77	74	71	60	55
Dead spruce branches	50	58	44	26	6	4
Hardwood foliage	50	62	56	48	42	38

Table 3. Residual amounts of attractant in flakes collected from the field at various intervals after application was completed on 26 June.

Date	Days after application	μg/flake[a]	Loss (%)
26 June a.m.	0	836.2	
26 June p.m.	.5	575.5	31.2
28 June	2	605.8	27.6
29 June	3	579.4	30.7
2 July	6	495.5	40.7
6 July	10	438.2	47.6
14 July	18	302.9	63.8
21 July	25	261.6	68.7

[a]Average of 20 flakes

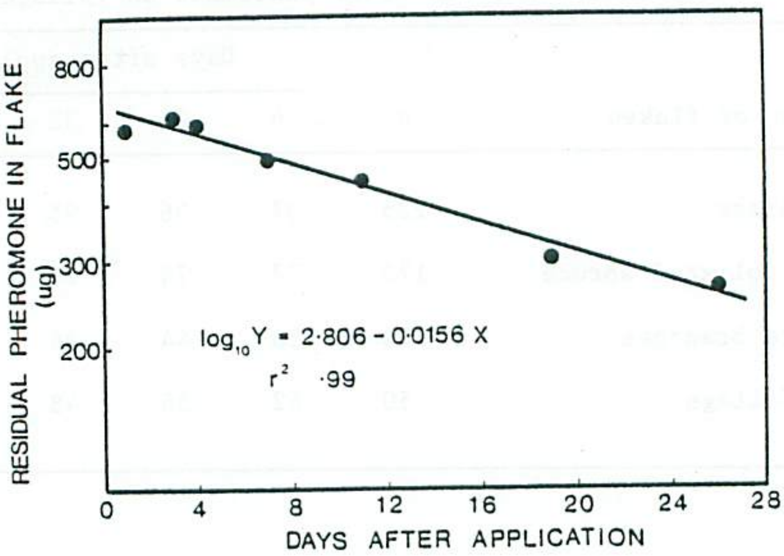

Figure 2. Residual amounts of pheromone in flakes collected from foliage in the treated plot at various intervals after application.

ant, and then extracting the resin and quantitatively analyzing the extracted attractant.

Details of this technique have been described elsewhere (Weisner and Silk 1982). Briefly, a sampler containing 20 g of resin was suspended at a height of 8-10 m in the stand. Air was passed through the resin by a pump at a rate of 59 m^3/hr for 2 hr (1600-1800). The resin was then placed in a sealed jar, transferred to the laboratory and stored at -11°C until the end of the experiment when all samples were shipped in a styrofoam cooler to RPC for quantitative analysis. The attractant was extracted from the resin and analyzed by GC & MS operating in the full scan and MID mode. Quantities of attractant as low as 2 µg could be detected by this method which, at the pumping rates used, translates to about 200 picograms/m^3. Experiments were carried out to demonstrate that, with the quantities of resin used, breakthrough did not occur (i.e., all the attractant was absorbed by the resin).

Results are shown in Table 4. The attractant was detectable up to 10 days after application; the fact that it was not detectable thereafter means that it had dropped below a concentration of 200 picograms/m^3.

Table 4. Concentrations of attractant in atmospheric samples.

Date	Days after application	Concentration of attractant (picogram/m^3)
30 June	4	430
6 July	10	240
14 July	18	ND[a]
21 July	25	ND
27 July	31	ND

[a]Not detectable

WEATHER AND BUDWORM PHENOLOGY

Climatic parameters for the months of May, June, and July 1981, recorded at Sault Ste. Marie airport, are summarized in Table 5 and compared to the 30 yr average values.

Predicted phenology, based on weather data collected in 1981 at Kirkwood (north of Thessalon) adjacent to the check plot, is shown in Figure 3.

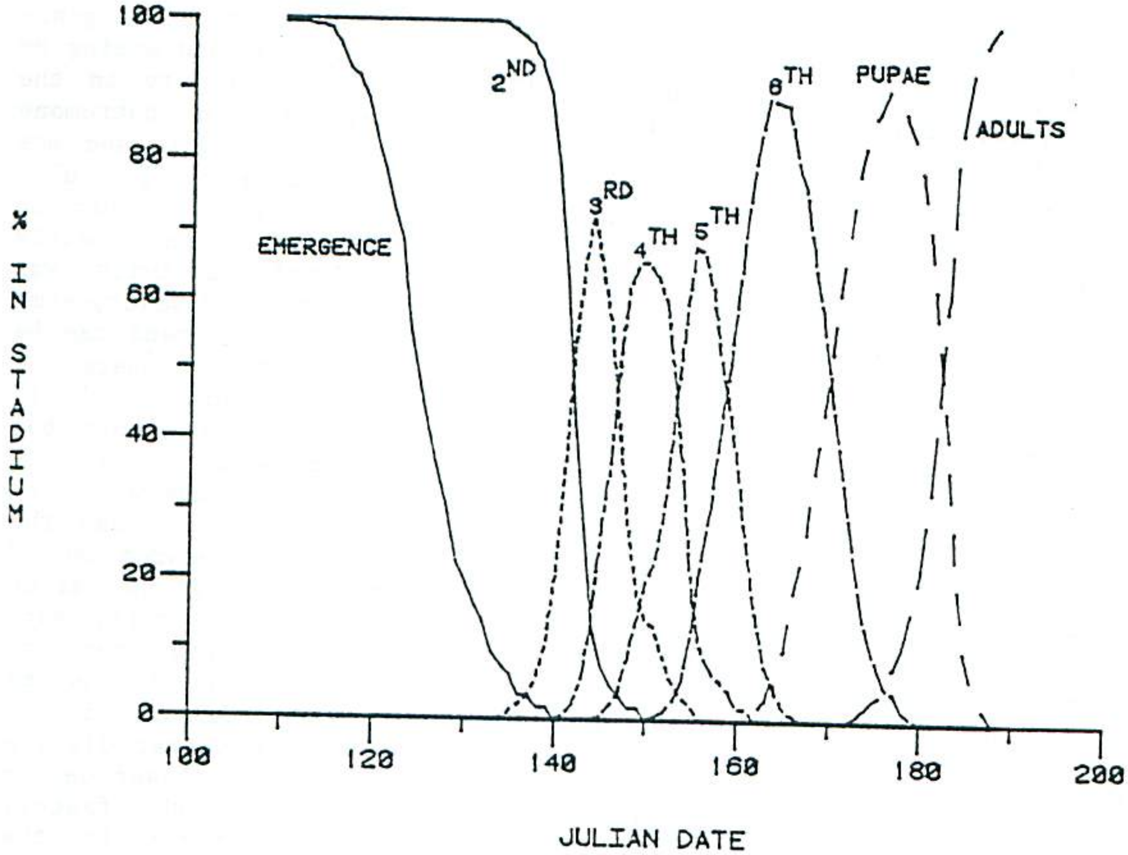

Figure 3. Budworm phenology in experimental area, 1981, predicted from local weather data (courtesy J. Régnière, Great Lakes Forest Research Centre, Sault Ste. Marie).

Table 5. Summary of 1981 weather recorded at Sault Ste. Marie, Ontario airport, compared to the normal (average of past 30 years).

	Mean temperatures (°C)				Total precipitation (mm)		Total sunshine (hr)	
	Maximum		Minimum					
	1981	Normal	1981	Normal	1981	Normal	1981	Normal
April	9.3	8.3	-1.2	-1.8	78.6	56.1	178	186
May	16.0	15.2	3.2	3.1	31.6	82.3	228	246
June	20.1	21.1	7.4	8.0	151.9	88.4	195	265
July	25.5	23.9	11.4	11.2	39.8	71.1	298	288

Although average temperatures in April and May were close to normal, daily temperatures fluctuated quite widely. As a result, budworm emergence was spread over a long period with a wide range of instars present at any one time, a pattern which persisted until early June. The latter half of May was cool, and this slowed development. On 4 June most larvae were in the 4th instar, with some small thirds and a few sixths. On 12 June a sample yielded 71% 6th, 11% 5th, 17% 4th, and 1% 3rd instars (close to what was predicted in Figure 3). June, although it had close to normal temperatures, was an extremely wet month, with almost twice the normal rainfall, and less than 75% of normal sunshine. This was associated with a heavy fungal infection of the budworm population (see section on Biological Assessment). The first male moth was captured in a pheromone trap (a very sensitive detection method) on 28 June. Figure 3 predicts moth emergence starting on 20 June and ending by 12 July. Male activity in the field, monitored in pheromone traps, peaked on 8 July and was virtually complete by 20 July, although the traps continued to catch some males into early August. Female activity was harder to monitor. However, some indication of development can be obtained from the numbers of spent females captured on horizontal sticky tables (Table 6). The first female moth was captured on 3 July, numbers peaked between 9 and 13 July, and the last female was captured on 23 July. The adult flight period was therefore very abrupt, more so than was expected from the wide spread of larval instars found in early June. It is therefore suspected that disease killed more of the slower developing insects than the faster, thereby effectively removing the later insects from the population.

Table 6. Numbers of spruce budworm moths captured on horizontal boards covered in Bird Tanglefoot in check plot, 1981.

Date	Moths trapped	
	♂	♀
July:		
1	0	0
3	4	1
7	13	1
9	28	32
13	81	38
15	7	12
17	10	3
20	5	3
23	2	1
27	2	0
31	3	0

BIOLOGICAL ASSESSMENT

Larval/Pupal/Egg Sampling

An estimate of pre-spray larval densities was made during the 4th instar on 4 June. Further assessments of population density of larvae/pupae, indicating expected numbers of adults, were made on 8, 11, 14, 17 and 21 July. Estimates of egg densities were made on each of the above dates, with a final estimate on 25 August. The sampling unit throughout was a 45 cm branch tip taken from two thirds of the way up the living canopy of the trees (Table 7).

The initial larval populations (4 June) were of moderate density and were not significantly different in the treated and check plots. However, as can be seen from Table 7, the population subsequently crashed. In the check plot the July samples averaged only 0.23 emerged pupae/branch (approximately $2.3/m^2$, or a 98% reduction), while in the treated plot the figures were 0.45/branch ($4.5/m^2$, or a 96% reduction). This population decline was due largely to a heavy fungal infection induced by the extremely wet June (D. Tyrrell, Forest Pest Management Institute, Sault Ste. Marie, pers. comm.). Resulting egg masses were very low in number, but the data do suggest that until 21 July fewer eggs were laid in the treated plot than in the check, in spite of higher populations of adults in the former. However, the final estimates on 25 August show no significant difference between plots.

Trapping of Moths

Pherocon 1C traps baited with synthetic pheromone were deployed in both check and treated plots. Two concentrations of lure were used, .03% by weight (equivalent in potency to a virgin female) and .0003%. The traps were deployed in random sequence in a 5 x 6 grid with 20 m between traps, ten of each concentration and ten unbaited checks in each grid. Half the traps were suspended in the canopy (about 10 m above the ground), while the other half were suspended at head height (2 m). Two such grids were laid out in the treated plot, one in the check plot.

Daily catches, corrected for catches in the check traps, are shown for the canopy in Figure 4, and for the ground traps in Figure 5. Catches in the check traps alone were low (Fig. 6). Because of saturation of the trapping sur-

Table 7. Estimates of larval/pupal populations before and after treatment, and egg mass numbers after treatment in check and treated plots (± 1SE).

		Before treatment	After treatment					
		4 June	8 July	11 July	14 July	17 July	21 July	25 Aug.
Check plot	n	25	25	10	10	10	10	40
	larvae/pupae[a]	12.6 ± 1.2	0.20 ± .10	0.20 ± .13	0.10 ± .10	0.10 ± .10	0.60 ± .21	–
	egg masses	0	.04 ± .04	.50 ± .25	.40 ± .21	0	.30 ± .20	.75 ± .15
Treated plot	n	25	25	10	10	10	10	40
	larvae/pupae[a]	10.8 ± 1.3	.36 ± .12	.80 ± .46	.40 ± .29	.50 ± .29	.40 ± .21	–
	egg masses	0	0	.10 ± .10	0	0	.30 ± .14	.78 ± .15

[a]Includes emerged pupal cases.

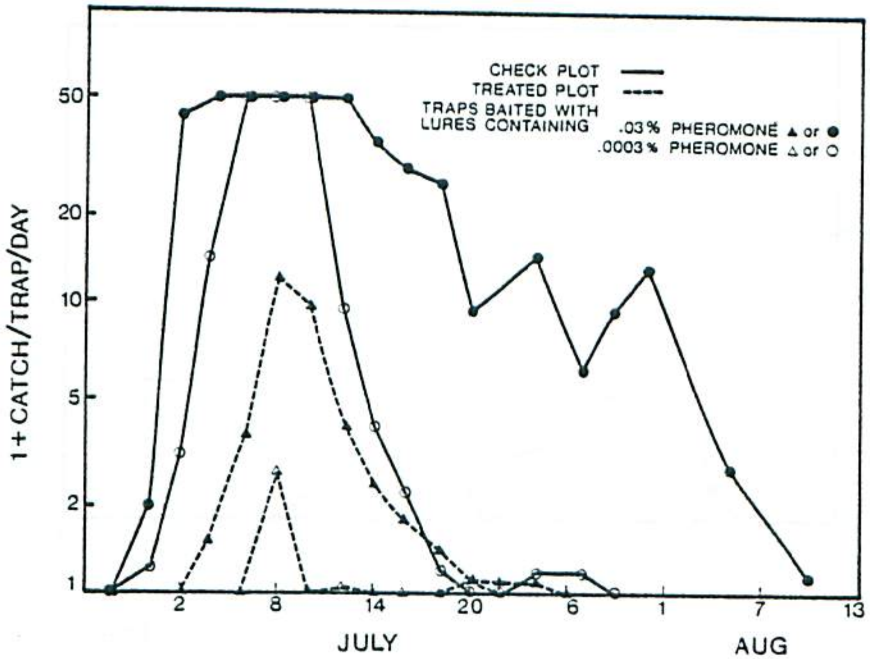

Figure 4. Daily catches of male budworm moths in Pherocon 1CP traps baited with pheromone, deployed in the canopy in treated and check plots.

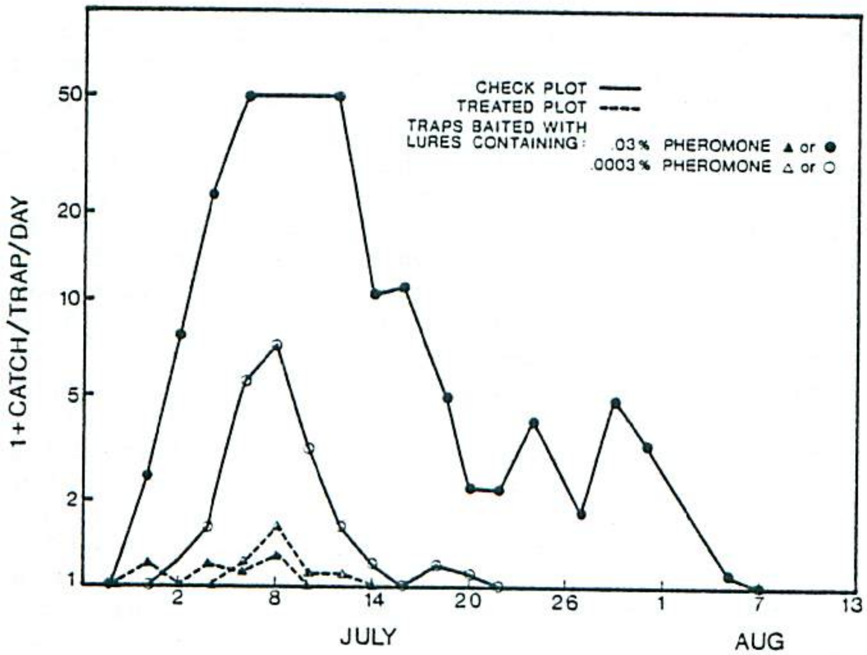

Figure 5. Daily catches of male budworm moths in Pherocon 1CP traps baited with pheromone, deployed at a height of 2 m in treated and check plots.

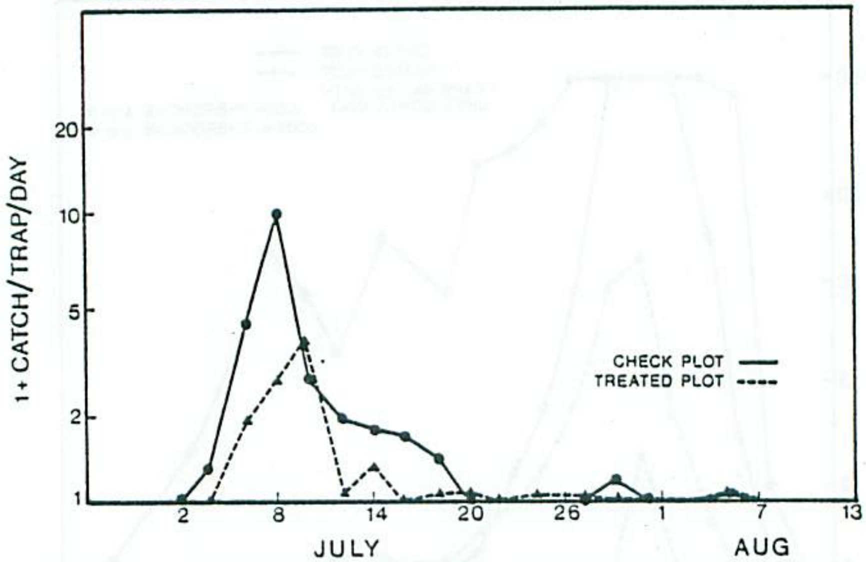

Figure 6. Daily catches of male budworm in unbaited Pherocon 1CP traps in treated and check plots.

faces in the check plot during peak flight it is not possible to calculate the percent reduction in catches, but it is evident that reduction was profound, probably well in excess of 90%. However, in spite of this reduction, significant numbers of males were still able to locate the lures in the treated plot, especially those in the canopy.

Catches in the check traps for the treated and untreated plots are compared in Figure 6. If activity levels independent of attraction were the same in both plots, catches should be similar, or possibly slightly higher in the treated area because of higher moth densities. However, catches were significantly lower in the treated area, indicating an overall suppression of activity, presumably because of the presence of the synthetic sex attractant.

Mating Cages

Laboratory-reared male and female budworm moths were placed in cages which were then deployed in treated and check plots. The moths were left in the cages in the field for two days. The females were then dissected to detect the presence of spermatophores (evidence of successful mating). Each cage was 1 m^3, constructed of 5 x 2.5 cm wooden frames covered in cloth mesh screen. Three different proportions of male to female budworm were used in different tests, two males to one female, four males to three females, and nine males to six females. In each test the males were 2 or 3 days old, the females 1 or 2 days old. Releases and collections were made during the morning. Foliage was included in the cages with the moths. The cages were hauled up into the canopy 6 to 10 m off the ground. A total of 12 cages were used, 6 in the check, 6 in the treated area. Results are shown in Table 8. At all three moth densities mating reduction in the treated areas was significant, averaging approximately 40% in each case. No differences were found to be attributable to moth density, which is in contrast to previous results reported by Schmidt et al. (1980). Possibly in the current experiment failure to show an effect associated with moth density was due to the differing male to female ratios, or to the fact that the highest density was run first when the atmospheric titre of attractant was highest, and the lowest density was run last.

Mating Status of Wild Females

The original plans called for the collection of female moths at regular intervals from both check and treated plots by spraying trees with insecticide and collecting the dead insects on drop sheets so that their mating status could be examined. Dr. P.C. Nigam of the Forest Pest Management Institute in Sault Ste. Marie recommended and provided Permethrin for this purpose, to be used at a concentration of 0.1% in water.

On 3 July, two pairs of white spruce in the treated plot which were well foliated down to ground level, were sprayed from the top down, with a gasoline-powered backpack mist blower from the platform of a bucket truck. In the 30 min. following insecticide application, two females and one male were found on the drop sheet under one pair of trees, but only one female was found on the other. All three females contained a single spermatophore. The yield from this technique was disappointingly low, presumably because of the low moth density following the population collapse, and no further spraying was carried out.

On 8 July two men using a bucket truck spent 4 hr catching spruce budworm moths in collecting nets from the crowns of the spruce. They banged the rims of the nets against the underside of the branches, causing moths either to fall into the net or to take flight. Attempts were made to catch all those that flew. A total of 18 female moths were captured by this technique in the treated plot, and all of them contained single spermatophores. While it is possible that this sampling technique was biased in favor of catching mated moths, it does illustrate that a large number of females were mated in the treated area.

Behavioral Observations

Moth behavior in the field

In general, observations and analysis of moth behavior in the field were confounded by the low populations resulting from the decline in larval populations. As already mentioned, observations were facilitated by the erection of 16.5 m high scaffolds in the

Table 8. Numbers of female moths mating when confined with males in 1 m^3 screen cages for 2 days in check and treated plots.

♀:♂ Ratio	Date (July)	Check: No. of females Recovered[a]	Check: No. of females Mated	Check: Mating (%)	Treated: No. of females Recovered[a]	Treated: No. of females Mated	Treated: Mating (%)	Reduction in mating (%)
6♀:9♂	2	36	34	94	36	20	56	40
	4	36	34	94	34	16	47	50
	6	29	23	79	34	17	50	37
	Avg.			89 ± 4.1			51 ± 2.2	42
3♀:4♂	8	15	9	60	13	6	46	23
	10	17	13	76	18	6	33	57
	12	18	15	83	16	6	38	54
	22	16	10	63	17	7	41	35
	29	17	14	82	18	6	33	60
	31	15	8	53	18	10	56	-5
	Avg.			69.5 ± 4.7			41.2 ± 3.3	37
1♀:2♂	16	6	3	50	5	2	50	20
	18	5	4	80	6	4	67	16
	20	4	2	50	3	1	33	34
	24	4	4	100	4	1	25	75
	Avg.			70 ± 10.6			41.2 ± 7.9	36

[a]Where ratios of ♂:♀ were distorted by the presence of too many males or the absence of one or more females, the whole cage was excluded.

check and treated plots. Further observations were made from the bucket of a 13 m high bucket truck. Male activity was monitored from the scaffolds by counting the number of males visibly active around the top 3-4 m of five dominant or codominant trees. Counts were made by briefly scanning the five trees five times every 15 minutes. It was hoped that numbers would build up to those recorded in 1976 (a maximum of 24 males/five trees, associated with a high incidence of female dispersal) (Sanders, unpubl. data). Starting on 6 July, therefore, a single observer monitored activity in both check and treated plots, so that counts were not continuous in either plot. Peak counts averaged for the five scans were as follows: 6 July, 2.6; 7 July, 5.4; 8 July, 1.0; 9 July, 12. This suggested that there would be higher counts on 19 July, and so both scaffolds were manned. However, the highest counts on 10 July were four in the treated plot and six in the check plot. On 11 July they dropped to 1.6 and 1.0 and on 12 July counts in both plots were 0. Further counts were therefore discontinued.

On 5 July it was noticed that many males in the check plot were flying from tree to tree, and not hovering close to the foliage (buzzing) as they were in the treated plot. Therefore, on 6 July counts were kept of the two types of behavior. Of 42 males in the check plot only 11 (26%) were buzzing, but of 114 males in the treated plot 104 (91%) were buzzing. This may have been due to the fact that females had not emerged and hence no pheromone, either natural or artificial, was present to cause buzzing in the check plot, although buzzing was caused by the presence of synthetic pheromone in the treated plot. No such marked difference was noticed on 7 July or on subsequent evenings, possibly because females were then present in substantial numbers in both areas.

Observations were also made from the scaffold of responses of males to individual flakes of the formulation in the treated plot. On the evenings of both 5 and 6 July, males were seen wing-fanning or flying within 1 m of individual flakes, but no direct contacts were noted. Attempts to quantify this by recording numbers of males in the vicinity of flakes as opposed to elsewhere were unsuccessful because of the low numbers.

Attempts were also made to observe male response to caged virgin females on the evenings of 9 and 10 July. Females were placed out in each plot at various heights on the scaffolds. In the check plots a total of 11 males were recorded at the cages, all at the three highest levels. None were recorded at the cages in the treated plot.

Despite very careful observation, no female dispersal from the plots was detected.

Response of males to flakes

To assess the potential of the formulation for disrupting mating, the potency of individual flakes in competition with virgin female moths was assessed in the field.

Flakes were collected from the field 14 and 28 days after application. These were pinned individually inside Pherocon 1CP traps which were then deployed on grids, with either 5 m or 10 m between traps, along with traps baited with virgin females. Results (Table 9) indicate that, although the synthetic sources caught many more moths than did the females, most females attracted some males and at some stages of the evening some females caught more males than did the synthetic lures. Thus, at the spacings used, 5 or 10 m, the flakes could not completely prevent males from locating at least some of the females. The evidence, therefore, is that although the flakes were more attractive to males than was the average female, there were individual females which, for at least short periods, out-competed the lures.

Table 9. Catches of male spruce budworm moths in Pherocon 1CP traps baited with a single 2-day-old virgin female or with Hercon flakes collected from the treated plot 14 or 28 days after application, showing average hourly catches and the range.

Spacing	Lure	n	Time 1800	1900	2000	2100	2200	2300
5 m	♀	9	1.7 (0-5)	0.2 (0-1)	0.9 (0-4)	3.0 (0-20)	5.0 (0-14)	0 (0)
	14-day-old flake	5	26.6 (5-50)	22.0 (1-50)	8.6 (3-18)	11.6 (1-32)	15.4 (4-35)	0.2 (0-1)
	28-day-old flake	5	20.0 (5-50)	12.4 (3-50)	3.2 (0-9)	5.2 (2-12)	4.6 (2-9)	1.0 (0-4)
10 m	♀	10	1.7 (0-9)	0.7 (0-3)	0.5 (0-3)	1.2 (0-3)	2.2 (0-5)	0.1 (0-1)
	14-day-old flake	5	11.0 (3-25)	12.0 (1-23)	10.4 (3-27)	7.4 (2-16)	3.8 (1-7)	0 (0)
	28-day-old flake	5	4.0 (2-7)	1.4 (1-2)	10.2 (5-16)	3.6 (0-10)	3.4 (1-7)	0.2 (0-1)

Behavioral evaluation of the formulation in a wind tunnel

The ability of the males to locate calling females in the presence of flakes was also evaluated in a wind tunnel.

Two virgin female moths, programmed on a light-dark cycle to call at 1500 hr, were housed in small screen cages fastened to a wire stand. This stand was moved to the upwind end of a glass wind tunnel, 90 x 90 cm in cross section. One of the Hercon flakes was then fastened to another wire stand which was placed alongside the female. Smoke tests indicated that the time-averaged plume from flake or females was about 25 cm in diameter 190 cm downwind (the release point of the males). Males were released individually, and records were kept of male behavior, in particular how many males reached the females or the flake. In test 1 the flake was 40 cm off to the side of the females and the males were released individually one quarter of the distance between the direct wind lines from the flakes and from the female (i.e., 10 cm off the female wind line) so that the male was in the female plume. In test 2 the flake was again 40 cm off to the side of the females so that the two plumes again just overlapped. The males were released halfway between the direct wind line from the flake and the female (20 cm off the direct wind line, just in the overlapping area of the plumes). In test 3 the flake was positioned 20 cm to the side of the females so that the plumes overlapped more than halfway down the tunnel. Males were released halfway (this time 10 cm) between the direct wind lines from flake and female, i.e., in the overlapping portion of the plumes. These three tests were run with flakes ranging in age from 1 to 3 weeks. While the above three tests simulated a female close to the flake in a field situation, they did not include the effects of the permeation of the atmosphere by pheromone released by other, more distant, flakes. Therefore, the experiment was repeated in the presence of a background of pheromone uniformly permeated throughout the tunnel.

The concentration for the uniform permeation was based on that measured in the field during the field trial. The analysis of atmospheric concentration in the field gave a figure of 0.4 ng/m^3 early in the experiment (Table 4). Previous calculations (Sanders 1982) indicated that 81 pellets of PVC, each containing about 40 μg (.03% by weight) placed behind the upwind screen, would give a concentration in the working area of the tunnel of about 1 ng/m^3. In order to err on the conservative side, this concentration was therefore used in these experiments.

The results showing the percentage of males reaching the female under the various conditions are given in Table 10.

With a background of clean air, males released into the female plume showed a high success rate, ranging from 93% in the presence of a 3-week-old flake to 47% in the presence of a one-week-old flake. The success rate dropped as competition between flakes and females increased when

Table 10. Percentages of male budworm reaching calling virgin female moths which were in competition with Hercon flakes in a wind tunnel.

Treatment		Background of clean air: Flake 7-9 days old	Background of clean air: Flake 16-18 days old	Background of clean air: Flake 23-25 days old	Background of pheromone: Flake 16-18 days old
1. Flake and ♀ 40 cm apart ♂ released 150 cm downwind in ♀ plume	n	15	15	15	22
	% reaching ♀	47	80	93	5
	% reaching flake	27	20	0	9
2. Flake and ♀ 40 cm apart ♂ released 150 cm downwind in area of plume overlap	n	30	30	30	30
	% reaching ♀	13	27	43	5
	% reaching flake	53	40	30	17
3. Flake and ♀ 20 cm apart ♂ released 150 cm downwind in area of plume overlap	n	30	30	30	30
	% reaching ♀	13	30	43	0
	% reaching flake	53	47	33	10
4. As in treatment 1, but ♂ released 25 cm downwind of ♀.	n	-	-	-	15
	% reaching ♀				40
	% reaching flake				0

the two were moved closer, but even where the females were only 20 cm from a flake and the males were introduced into the overlapping area of the plume, 13% of the males still arrived at the females vs 53% at the flakes. A similar situation in the field, particularly at high population densities, would ensure that most females were mated.

In the presence of the background pheromone at 1 ng/m^3 the success rate dropped dramatically. When released 150 cm from the pheromone source (either flake or females) only 10-20% of the males reached a source and only 5% of the males located the females, even when released in the female pheromone plume. In these conditions the results would suggest that disruption should be quite effective. However, when the males were released at a distance of 25 cm from the females, 40% located the females. The conclusion is, therefore, that at the densities experienced in the field in 1981, sufficient males in the course of normal, non-pheromone-related activity will have come close enough to the females so that many of the females will have been successfully mated. The chances of this happening are clearly related to population density, and this suggests that disruption will be increasingly effective as population density decreases.

CONCLUSIONS

1. The method of dispersing flakes and sticker from the aircraft was very effective and gave good distribution of the flakes.

2. Comparison between the number of flakes on drop sheets and the number on the foliage suggests that only 5-10% of the flakes falling onto the foliage adhered to the foliage. This implies that the sticker (a water emulsion of polybutene) is not sticky enough to hold the flakes on impact.

3. Measurement of release rates from flakes and of concentrations of pheromone in the atmosphere suggest that the formulation emitted pheromone as specified over the course of the experiment, but since the polybutene and pheromone are known to be intersoluble, in theory pheromone may move from flake to sticker, thereby altering release rates. Consequently, this point requires further checking.

4. Biological assessment was confounded by the fact that adult numbers were lower than planned because of a collapse in the population caused principally by a fungus disease.

5. Both trap catches and mating cages, however, indicated that the treatment did reduce mating.

6. Egg sampling suggested a delay in oviposition in the treated plot although final egg populations did not differ from those of the check.

7. Behavioral observations in the field were inconclusive because of low numbers of adults.

8. Field trapping and wind tunnel experiments indicated that males can still find some of the females even with high background concentrations of pheromone, and even when the females are close to a flake in the field.

9. Refinements in pheromone concentration and distribution are urgently required and should be made in the laboratory in a wind tunnel supplemented by small-scale field tests before further trials of this type are carried out.

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