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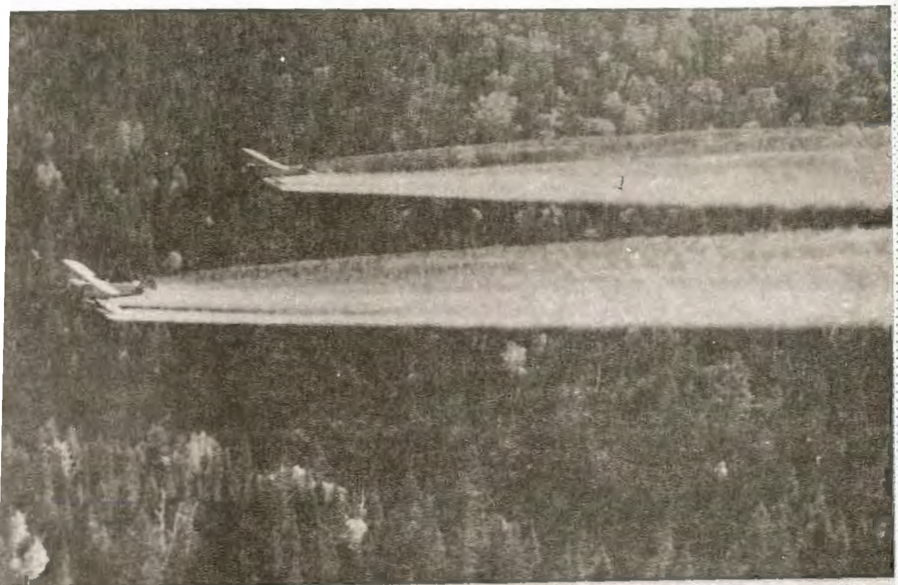

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MARITIMES

CANADIAN FORESTRY SERVICE

MARITIMES FOREST RESEARCH CENTRE

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ABSTRACT

Aerial spraying tests against spruce budworm moths were conducted from 1972 to 1977 in New Brunswick. A varying number of applications of 70 g phosphamidon per hectare killed more than 70% of the males (mating status unknown) and a relatively larger proportion of old females that had laid more than 50 to 60% of their eggs. No effective means were developed to kill young females. However, in a test specifically designed to kill emerging males and disrupt mating, 41% of the female population died as virgins, and it was estimated that the oviposition rate in the treatment block was reduced by 50%. The highest reductions in egg deposition, 64, 69, and 72%, were attained when more than 3000-ha blocks were treated with two applications of 140 g phosphamidon per hectare.

Environmental monitoring of the trials produced evidence of moderate to severe mortality in populations of many species of fir-dwelling insects, mites and spiders vulnerable to low-dosage sprays of fenitrothion, aminocarb and phosphamidon in early to mid July. Most of the mortality took place in the first 2 days and included especially moths, hymenopterous parasitic wasps, flies, beetles and sucking bugs. As expected, rates of kill were greater with higher dosages and more applications, but even light treatment caused much more dramatic kill than larvicidal sprays in May. Some specificity occurred according to insecticide e.g. aminocarb was more lethal to spiders. Accumulative mortality of predaceous insects and

RESUME

Des essais d'arrosage aérien d'insecticides contre les papillons de la Tordeuse des bourgeons de L'Epinette ont été effectués entre 1972 et 1977 au Nouveau-Brunswick. Un nombre varié d'applications de 70 g de phosphamidon à l'hectare ont uté plus de 70% des mâles (état d'accouplement inconnu) et une proportion relativement plus élevée de vieilles femelles qui avaient pondu plus de 50 à 60% de leurs oeufs. Aucun moyen efficace n'a été mis au point pour tuer les jeunes femelles. Cependant, lors d'un essai conçu spécifiquement pour tuer les jeunes mâles et perturber l'accouplement, 41% des femelles vierges sont mortes et on estime que le taux de ponte dans le secteur traité a été réduit de 50%. Les plus importantes réductions de la ponte des oeufs, soit 64, 69 et 72%, ont été obtenues par le traitement de blocs de 3 000 ha avec deux applications de 140 g de phosphamidon à l'hectare.

La surveillance environmentale des essais a laissé entrevoir une mortalité moderée-à-sévère dans les populations de beaucoup d'espèces d'insectes, de mites et d'araignées habitants du sapin et vulnérables aux arrosages de fénitrothion, aminocarb et de phosphamidon à une dose faible dans la première moitié du mois de juillet. La plupart de la mortalité a eu lieu pendant les premiers deux jours et a compris surtout les papillons, les guêpes hyménoptères parisites, les mouches, les coléoptères, et les punaises suceuses. Comme prévu, les taux s'augmentaient mites and hymenopterous parasitoids sometimes exceeded 90% after three applications. The rates of population recuperation were not generally investigated, but parasitism in small larval budworm one year after spraying remained within the normal rates expected in untreated forest.

selon les dosages et le nombre d'applications. Cependant, même un traitement léger a entraîné une mortalité beaucoup plus dramatique que celle occasionée en mai par les herbicides pulvérisés. Quelque spécificité a été observée selon l'insecticide; par exemple, l'aminocarb était plus mortel aux araignées. La mortalité cumulative chez les insectes et mites rapins et les parasitoïdes hyménoptères dépassait parfois 90% suivant trois applications. Les taux de régénération n'ont pas été généralement étudiés, mais le parisitisme chez les petites larves de la tordeuse des bourgeons de l'épinette ne dépassait plus la norme prévue pour la forêt nontraitée un an après la pulvérisation.

INTRODUCTION

Suppression of a population of spruce budworm, *Choristoneura fumiferana* (Clem.), by spraying the moths with insecticide was first tested in New Brunswick by Forest Protection Limited under the direction of B.W. Flieger. Small-scale tests were carried out in the mid-1960's followed by a treatment on 7000 ha in 1969. In 1972, Forest Protection Limited and the Maritimes Forest Research Centre set up a joint program to evaluate moth spraying. The results of six joint test programs are summarized in this report.

The aim of moth spraying is to minimize egg deposition. This, in theory, entails the treatment of both resident moths and dispersing moths that could invade a protected forest. Invading moths could be treated in several ways: (1) Use radar (airborne or a grid of ground- based units) to track dispersing moths and, if necessary, place a 'curtain' of spray around a protected forest to prevent incursion. (2) Use radar to locate concentrations of moths, particularly in association with air-mass disturbances, and spray the moths in the air. (3) Use radar or a grid of ground-based monitoring devices to determine if airborne moths descend into a protected forest and, if the invaders are numerous, spray them on the ground. (4) Disrupt the dispersal process of moths by spraying those source sites from which invaders into the protected forest would ordinarily originate. Spraying techniques designed to disrupt mating also disrupt dispersal. Virgin females, and therefore gravid females, do not disperse.

Most of the moth spray trials conducted between 1972 and 1977 were air-to-ground sprays timed to kill a maximum number of resident moths (Miller *et al.* 1973, Miller *et al.* 1976, Thomas *et al.* 1979). The objective of the treatments was to find the most efficient way to kill the adult by varying the insecticide, dosage, and time of treatment. There was one 'air-to-air' spray trial in which a curtain of spray was used to determine the reaction of moths to the spray cloud and the deposition of insecticide on moths that penetrated the cloud. In general, however, airborne moths were considered an elusive target that poses a threat to a protected forest, yet at times may settle harmlessly into non-productive areas. Thus, it is doubtful if air-to-air spraying of budworm moths will be used extensively until effective methods (airborne radar plus ground-monitoring devices) are developed to determine the 'invasion risk' of an airborne population.

METHODS

The moth spray tests (Table 1) generally were carried out in heavily-infested forests, with an effort being made to avoid larval spray areas and thus minimize double-treatment zones in any one season. Treatment blocks ranged from 120 to 8000 ha and in 1974, an operational spray covered 800 000 ha. Usually 10 plots consisting of five fir, *Abies balsamea* L. Mill. and five spruce, *Picea* spp. trees were laid out in the treatment blocks and at check points. Counts of pupae, pupal cases, egg masses, and in some instances, overwintering larvae were obtained. The sample unit in each case was one midcrown branch per tree.

Sticky-traps baited with budworm sex attractant were used to measure male abundance, before and after treatment. The traps were constructed from cardboard milk cartons with the ends removed and the inner surface smeared with an adhesive. Five to 10 traps were used per plot.

Dead moths were collected in drop trays and in some instances the

Table 1. Summary of treatments and objectives in adult spray trials 1972-1977

Year	Treatment	No. of applications	Block size (ha)	Objective
1969*	140 g phosphamidon in 1.46 L/ha	2X	7 000 (1)**	Are adults feasible spray targets?
1972	Phosphamidon and fenitrothion; 140 g in 1.46 L/ha	2X	3 000 (2)	To compare fenitrothion and phosphamidon
1973	Phosphamidon in 0.88 L/ha		8 000 (16)	To compare (a) early and late application (b) 35, 70, 140 g per ha (c) one and two applications
1974	70 g phosphamidon in 0.88 L/ha	2X	29 000 (DC-6B) (11) 15 000 (TBM) (33)	Operational spray on 800 000 ha
1975	70 g phosphamidon in 0.88 L/ha		700 (12)	To compare in replicated experiments (a) early and late application (b) two, three, and five applications
1976	Aminocarb and phosphamidon; three applications of 70 g/ha. Orthene; two applications of 280 g/ha. Sevin-4-oil; one application of 1120 g/ha., two applications of 560 g/ha (in 0.73 L/ha)		240 (10)	To compare (a) aminocarb, Sevin-4-oil, Orthene, and phosphamidon (b) persistence of Sevin
1977	70 g phosphamidon/ha in 0.73 L/ha	3X	3 000 (1)	To test the effectiveness of an early spray to kill males
1977	70 g phosphamidon + 1.7 g pyrethrin + 7 g piperonyl butoxide/ha		120 (1)	To test effectiveness of phosphamidon plus a motor stimulant

* 1969 Trial by Forest Protection Ltd.
** Number of blocks in brackets.

females were examined for mating and oviposition status (Thomas 1978). The drop trays were of variable design, from polyethylene sheets subtending half a tree crown, to triangular trays (1.5 x 0.8 m base) subtending 5 to 10% of a crown.

In 1974, 1976, and 1977, light traps were set up to compare moth abundance in spray and check blocks and to monitor invading moths. The traps were placed at midcrown level within the crown canopy and in clearings. It was assumed that catches made in traps in clearings would provide indication of invasion.

Observation platforms, 5 - 20 m high, were erected in the spray and check blocks in 1972, 1973, and 1976 from which the number of flying budworm moths were recorded every 15 min from 1830 h ADT to last light, about 2130 h. Within each time interval, the males buzzing around the top 2 m of a selected balsam fir crown were counted 10 times. The female count consisted of a 2-min tally of those moths taking-off in downwind dispersal from a cluster of 10 trees. Data from a night-viewing device suggest that visual observations (1830 to 2130 h) covered 35% of the total flight activity on warm nights (20°C at 2000 h) and 100% of the activity on cool nights (18°C at 2000 h).

In 1976 and 1977, Malaise traps were set up at midcrown height to record moth activity and abundance, and to determine the oviposition status of captured females.

A ground-based radar unit was located within the spray block in 1974 and 1976. The objective in 1974 was to record moth abundance in the airspace and to estimate when the block may have been invaded by egg-carrying females. The objective in 1976 was to use radar counts in conjunction with light-trap counts to determine if moths observed on the radar screen descended into the spray area and if the density and oviposition potential of invading females warranted an application of spray as soon as possible.

A high-pressure sprayer capable of reaching the top of a 15-m tree was used in 1977 to kill moths in sample trees, to determine moth abundance and the mating and oviposition status of females. Trees were sprayed daily between 0600 and 0830 h and dead moths were collected from drop sheets about 30 h later.

RESULTS

Budworm adults emerge in late June and July depending on temperature. The time lapse between the first and last female emergence within a population is usually about 10 or 12 days (Fig. 1). The first adults emerge at about 530 units of heat (accumulated from 1 April above a threshold of 5.56°C) and under controlled conditions females live about 10 days. Sanders and Lucuik (1975) state that, on a daily basis at 20°C, peak emergence coincides with peak temperature and a female emerging in midafternoon begins to call shortly thereafter and mates by nightfall. The first eggs could be laid as early as the following afternoon and, under favorable conditions, 50% of her eggs would be laid by the end of the third day (Sanders *et al.* 1978). Field samples (using boiling water to wash unhatched egg masses from foliage) show that the first egg masses are found on the foliage three to four days after the first females emerge (as indicated by the first pupal cases recorded on branch samples), and 40 to 50% of the eggs are found when 100% of the females have emerged (Fig. 1).

Females that have laid some eggs respond to dispersal stimuli, particularly in heavily attacked stands (Greenbank 1973). They take off shortly after sunset, and radar observations show that they fly downwind for periods up to 6 h

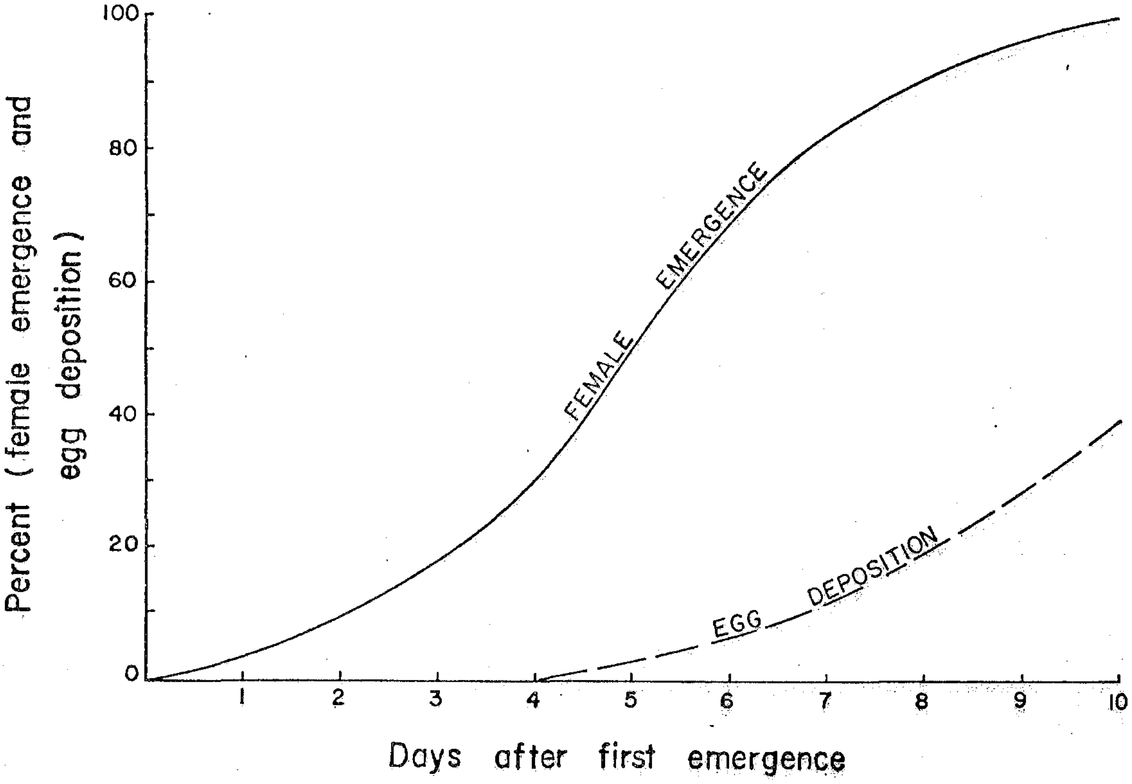

Figure 1. Relationship between female budworm emergence and eggs found on foliage.

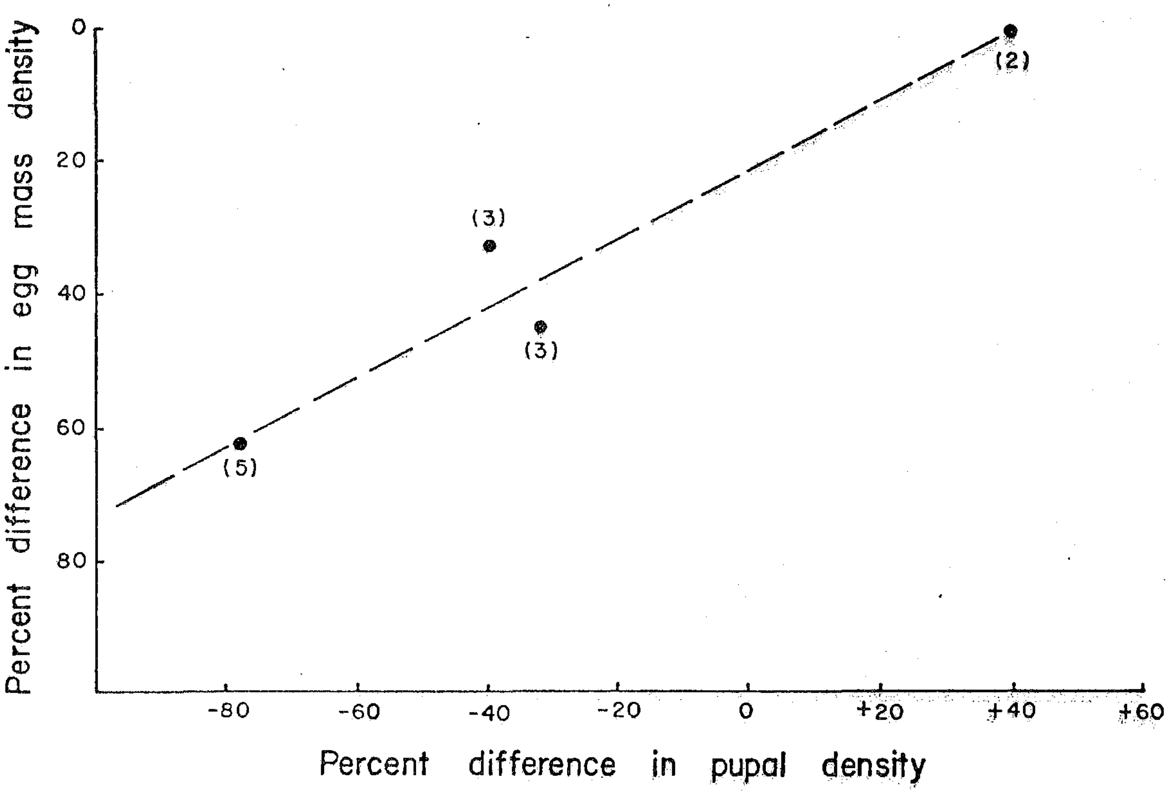

Figure 2. Data showing that spray plots with low pupal densities also had low egg-mass counts relative to check plots. Number of spray treatments in brackets.

(Schaefer 1976). Thus, if both resident females and egg-carrying invaders are the targets of a moth spray program, early or late invasions relative to the emergence of resident females could create problems in both timing and frequency of treatments.

Chemical adulticides

No systematic screening was carried out to find the most effective chemical to kill budworm adults. Small-scale laboratory tests in 1972 indicated that budworm adults were as susceptible to the topical application of phosphamidon as fourth-instar larvae, and more than twice as susceptible as sixth-instar larvae; males were more susceptible than females; and phosphamidon was more effective than fenitrothion. This latter result was confirmed in a field trial and phosphamidon, being readily available, was used extensively from 1972 to 1977 (Table 1.) Aminocarb, Sevin-4-oil, and Orthene were tested in 1976 and a formulation of phosphamidon plus a motor stimulant (pyrethrin mixed with piperonyl butoxide) was tested in 1977. The preliminary tests with Sevin and Orthene were disappointing but the one test with aminocarb suggested that on a gram for gram basis it was equally as effective, if not more so, than phosphamidon. The results of the motor stimulant test are discussed in a following section.

The most noticeable effect of phosphamidon on a moth population was that shortly after treatment, the males were the first to die. Some fluttering moths fell to the ground and died within a few hours of treatment but most males and old females succumbed within 24 - 48 h when treated with 70 g phosphamidon per hectare. The insecticide pathway is unknown. Healthy moths caged on foliage treated with a heavy dose of insecticide died within a few hours, apparently from walking on the contaminated foliage. But when adults were caged on field-collected foliage that had been treated at the operational rate of 70 g phosphamidon per hectare, none of the females died over a 4-day period, and mortality among the males was no different from mortality on untreated foliage. The insecticide pathway in an aerial spray would appear to be direct contact, with active males having a greater probability of coming in contact with a spray droplet and, because males are smaller than females, they may require a smaller lethal dose.

Number of applications

Tests to determine the most effective number of spray applications were conducted in 1975. A planned test in 1973 was aborted because of technical problems. In the 1975 tests, 70 g phosphamidon was applied to small test blocks of 700 ha or less. We would have preferred large test blocks to minimize boundary effects but costs were prohibitive. On small test blocks the results of two, three, and five applications were inconclusive. The total number of eggs laid in small treatment blocks tended to show that an increasing number of treatments resulted in an increased control, but the number of egg masses per resident pupa did not support this conclusion (Table 2). In fact, when the percentage reduction in eggs laid was plotted over the difference in the densities of resident pupae on treatments and checks, the data indicated that the fewest eggs were laid in blocks with the lowest number of resident females (Fig. 2). Thus the highest reductions in egg-mass densities were recorded in blocks with; (a) the highest number of applications of insecticide, and (b) the fewest resident pupae. The number of applications of insecticide cannot, therefore, be pinpointed as the

Table 2. Pupal, egg-mass, and overwintering larval densities on small blocks sprayed twice, three times and five times with 70 g of phosphamidon per hectare, and estimates of treatment effects

Year and treatment		Densities/10 m^2 Pupa	Egg masses	L_2	Ratio Egg masses /pupa (1)	L_2/pupa (2)	% control based on columns (1) (2) (1)	(2)
Two applications:								
1975	Spray	254	413		1.6		11	
	Check	181	328		1.8			
Three applications:								
1975	Spray	94	221		2.4		0	
	Check	181	328		1.8			
1976	Spray	83	208	377	2.5	4.5	22	41
	Check	120	380	916	3.2	7.6		
Five applications:								
1975	Spray	39	120		3.1		0	
	Check	181	328		1.8			

critical variable in these experiments. Nevertheless, the conclusion was reached in 1975 that a minimum of three applications would be required to cause a significant mortality among resident adults.

Dosage rate

The most consistent reductions in number of egg masses and overwintering larvae were obtained in 1972 and 1973; also in 1969 in a test conducted by Forest Protection Limited, when large blocks were treated with two applications of 140 g of phosphamidon per hectare. The analysis of egg masses per pupa showed good control ranging from 64 to 72% (Table 3). These results were significantly better than those obtained in 1974 when a large block was treated with two applications of 70 g/ha phosphamidon (Table 3). We conclude that 140 g of phosphamidon per application was much more effective than 70 g in killing egg-carrying females. However, because one of the objectives of the program was to use minimum amounts of insecticide per treatment, tests after 1973 were conducted with 70 g phosphamidon active ingredient per hectare.

Timing of treatment to kill resident moths

The 2- to 3-day differential in the emergence of males and females in a population raises the question: Is

Table 3. Pupal, egg-mass, and overwintering larval densities on large blocks sprayed twice with 70 g and 140 g of phosphamidon per hectare, and estimates of treatment effects

Year	Block	Densities/10 m^2 Pupa	Egg masses	L_2	Ratio Egg masses /pupa (1)	L_2/pupa (2)	% control based on columns (1)	(2)
140 g Phosphamidon								
1969	Spray	90	71		0.8		72	
	Check	84	240		2.9			
1972	Spray	43	360		1.0		64	
	Check	12	600		2.8			
1973	Spray	72	237	727	0.4	1.1	69	68
	Check	80	609	1637	1.3	3.4		
70 g Phosphamidon								
1974	Spray	53	496		2.0		23	
	Check	77	731		2.6			

it preferable to spray early in the season to kill males and thereby disrupt mating, or spray later to kill a maximum number of mated females? In 1974, part of the 800 000-ha treatment block was sprayed early when less than 20% of the females had emerged. There was no difference in the egg masses per pupa ratio and therefore we could show no difference between early and late sprays (Table 4).

In 1976, five blocks were sprayed twice with 70 g phosphamidon; two blocks were sprayed at about 20% female emergence and three blocks at about 75% female emergence (Table 5). Fewer egg masses per pupa were recorded in the late spray blocks suggesting that late sprays were more efficient.

In 1977, as the result of observations in 1974, 70 g phosphamidon per hectare were applied three times to a 3000-ha block with the objective of spraying early to kill males and disrupt mating. These early treatments were applied at 8, 60, and 85% male emergence (0, 40, and 70% female emergence). Resident pupal densities were variable, with the check block having a much lower density than the spray block. The mating status of dead females collected on the spray block was checked daily and, on average, 41% died as virgins (Table 6). Only 9% died as virgins in the check block indicating that the spray had a significant effect on mating success.

There was also an apparent reduction in egg deposition in the spray

Table 4. Pupae and egg-mass densities in early spray (<20% female emergence) and late spray (>60% female emergence) blocks, 1974

	Early spray	Late spray
No. of sample points	32	29
Pupae/10 m^2 foliage	347	172
Egg masses/10 m^2 foliage	600	329
Egg masses/pupa	1.7	1.9

Table 5. Pupae and egg-mass densities in early and late spray blocks, 1975

Plot	Female emergence	Counts/10 m^2 foliage		Ratio
		Pupae	Egg masses	Egg masses/pupa
Early spray				
A	20%	129	304	2.4
A1		360	879	2.4
Late spray				
C		277	270	0.97
C1	75%	249	519	2.1
C2		258	438	1.7

Table 6. Mating status of female moths killed in an early spray treatment, 1977

Date	Total no. of females	Frequency count of spermatophores per female				Virgin moths	
		1	2	3	4	Number	%
----Spray----			Spray			Spray	
July 12	8	5	2			1	12.5
13	10	8				2	20
14	33	22	4			7	21
----Spray----			Spray			Spray	
15	124	60	5			59	47.6
----Spray----			Spray			Spray	
16	98	39	4			55	56
17	325	189	13	1		122	37.5
18	287	119	8	2		158	55
19	67	33	1			33	49
20	96	42	7			47	49
21	88	38	1			49	56
22	56	21	1			34	61
23	12	6	2			4	33
24	130	84	13		1	32	25
25	95	57	22		1	15	16
26	73	47	11	1		14	19
27	12	10	1			1	8
28	9	7		1		1	11
29	17	12	2	1		2	12
	1540	799	97	6	2	636	
		52%	6%	1%	1%	41%	

block. Thus, in a sample of 1540 dead female moths, 636 died as virgins (no viable eggs) and wing length and body weight measurements showed that the remaining 904 mated females had laid an average of 111 eggs. Dividing the total number of fertile eggs (111 eggs x 904 mated females) by the total number (1540) of females examined, showed an average of 65 fertile eggs laid per female in the spray block. Similar measurements for the check block (143 eggs x 77 mated females/84 total females) gave 131 fertile eggs laid per female. The difference (131 to 65) indicated a 50% reduction in egg deposition. Treatment success based on the ratio of egg masses and second-instar larvae to pupal density suggested about a 40% reduction in oviposition (Table 7).

Although the evidence to support the tactic of spraying early to kill males is sketchy, the idea does warrant further testing, particularly the notion of increasing the applications from three to four to obtain better coverage of the male emergence period.

Table 7. Pupal, egg-mass, and overwintering larval densities on a large block sprayed early with 70 g phosphamidon per hectare and estimates of treatment effects

Year	Block	Densities/10 m^2 Pupae	Egg masses	L2	Ratio Egg masses /pupa (1)	L2/ pupa (2)	% control based on columns (1) (2) (1)	(2)
1977	Spray	115	146	246	1.27	2.14	44	38
	Check	86	196	296	2.28	3.44		

Differential kill of male and female moths

Except in 1976, the mortality of males exceeded 75% in all spray treatments. Catches of male moths in traps baited with sex attractant were analyzed by comparing the number of males caught after treatment to the number caught before treatment, to partially account for the variations resulting from differences in resident pupal densities and in trap locations within a plot. The data from four different treatments indicated that 64 to 95% of the males were either killed by the insecticide or were so affected that they did not react to the sex attractant (Table 8). There was no trend in the apparent rate of kill relative to dosage rate or to timing of application.

Light-trap catches also indicated a high mortality among males, 55% in 1976 and 86% in 1977 (Table 9), while visual counts from observation platforms of males flying in the twilight hours suggested that the insecticide resulted in an almost complete disruption of male activity (Table 10). This estimate is high compared to data from sex attractant traps and the difference probably arises from the difficulty in observing males at very low densities.

In summary, there is little doubt that three applications of 70 g of phosphamidon per hectare caused over 60% mortality of male moths in all tests although their mating success is unknown.

Mortality of females was more difficult to monitor because female activity is dependent on their mating status, age, and oviposition history. Measurements of female activity gave variable estimates of female mortality. For example, counts of females taking-off in dispersal flights suggested that this activity was reduced by 70 - 100% (Table 11), while counts of females in light traps and Malaise traps suggested that female mortality in treated blocks was low.

A better understanding of the impact of spray treatments on females was obtained when a method was developed to estimate the number of eggs a female had laid before succumbing to natural or induced death. The method was first used in 1976 and showed that females killed by three applications of 70 g phosphamidon per hectare had laid an average of 121 eggs, equivalent to 64% of their potential fecundity. Females killed by similar dosages of aminocarb had laid 70% of their potential (Thomas 1978). Females that had laid less than 50% of their eggs were rarely killed. A similar result was obtained in 1977 when three applications of phosphamidon (each 70 g

Table 8. Male catches in sex-attractant traps in spray and check plots and estimates of mortality

Year	Block	Males in traps Post-treatment (1)	Males in traps Pre-treatment (2)	Ratio (1)/(2)	Apparent kill,%
70g-2X*					
1973	Spray	53	333	0.16	81
	Check	600	706	0.85	
70g-3X					
1976	Spray	735	369	2.0	64
	Check	10,022	1,780	5.6	
1977	Spray	5,008	1,446	3.5	85
	Check	33,115	1,467	22.6	
140g-1X					
1973	Spray	73	680	0.11	87
	Check	600	706	0.85	
140g-2X					
1972	Spray	181	319	0.57	75
	Check	715	309	2.3	
1973	Spray	7	163	0.04	95
	Check	600	706	0.85	

* 2X = two applications

Table 9. Male catches in light traps in spray and check blocks, and estimates of mortality

Year	Block	Males in light traps Post-spray (1)	Males in light traps Pre-spray (2)	Ratio (1)/(2)	Apparent mortality %
1976	Spray	2701	427	6.3	55
	Check	6867	489	14.0	
1977	Spray	779	258	3.0	86
	Check	3652	170	21.0	

Table 10. Counts of buzzing males in spray and check blocks and disruption in this acitivty

Year	Block	Number of buzzing males Post-spray	Pre-spray	Ratio (1)/(2)	Apparent disruption in male activity %
1972	Spray	0	761	-	100
	Check	751	1456	0.52	
1973	Spray	2	336	-	100
	Check	272	1347	0.20	
1976	Spray	131	2202	0.06	97
	Check	6488	2817	2.33	

Table 11. The number of female moths taking-off in downwind dispersal flight in spray and check blocks, and reduction in this activity

Year	Block	Number of ascending females Post-spray (1)	Pre-spray (2)	Ratio (1)/(2)	Apparent disruption in female activity %
1972	Spray	41	246	0.17	77
	Check	104	141	0.74	
1973	Spray	0	14	-	100
	Check	33	53	0.62	
1976	Spray	29	41	0.71	94
	Check	69	6	11.5	

a.i./ha were applied to a 120-ha block. The first two applications, applied within a 13-h period, resulted in the death of females that, on average, had laid 55% of their eggs. The third application resulted in the death of females that, on average, had laid 70% of their eggs.

Early season applications of phosphamidon, timed to kill males and thereby disrupt mating, were carried out in 1977. These three applications also killed females, 41% of which died unmated. The peak mortality of these virgin females was on 17-18 July; the same as the peak mortality of mated females. The virgin females had laid 24% of their eggs whereas the mated females had laid 48%. There is a possibility that these two classes of females (virgin and mated) were of the same chronological age, and yet had died at different stages of ovipositing.

Our conclusion is that susceptibility of females to aerial sprays is related to chronological age. Females less than 2-days old are not susceptible. Unfortunately, by the end of the 2nd day of adult life a female will have laid 58% of her total egg complement (Sanders and Lucuik 1975). The implication for adulticide spraying is that sprays applied late in the season would kill many old females that had laid most of their eggs. Thus, their demise would have little impact on numbers of eggs deposited in the stand. On the other hand, spraying early in the season when most females were young and carrying most of their eggs would cause little female mortality and again would have little impact on number of eggs deposited.

Addition of motor stimulants to the spray formulation

The observation that few young female moths were killed by a dosage of 70 g phosphamidon per hectare led to the suggestion that an increased kill might be achieved by adding a motor stimulant to the insecticide to induce the young, somewhat sedentary, females to fly through the insecticide cloud. Laboratory experiments indicated that motor stimulants did increase activity (Volney and McDougall 1978) and this was followed by a small-scale field test in 1977 where 70 g of phosphamidon plus 1.7 g pyrethrin plus 7.0 g of piperonyl butoxide per hectare were applied to a 120-ha block.

Male moth catches in light traps and pheromone traps showed that mortality among males was greater than 65% and was slightly higher in the phosphamidon plus motor stimulant treatment block than in the block treated with phosphamidon alone (Table 12).

Table 12. Apparent mortality of males in phosphamidon and phosphamidon plus motor stimulant treatment blocks, 1977

Year	Treatment	Males in traps: Post-spray (1)	Males in traps: Pre-spray (2)	Ratio (1)/(2)	Apparent mortality %
Pheromone traps					
1977	Phosphamidon	228	55	4.1	66
	Phosphamidon plus stimulant	168	46	3.7	69
	Check	724	61	11.9	
Light traps					
1977	Phosphamidon	5947	1684	3.5	74
	Phosphamidon plus stimulant	4838	1898	2.5	82
	Check	18684	1375	13.6	

The oviposition status of the females collected in the treatment and check blocks is shown in Table 13. Females killed by the first application in the motor stimulant block had laid, on average, 59% of their eggs. Females dying after the last application (14 July) had laid, on average, more than 68% of their eggs. Most of the females that died in the check block had laid most of their eggs. Thus, in terms of our objective, the addition of the motor stimulant was not effective in killing young females.

Spray systems

The Grumman Avenger (TBM) is one of the most common aircraft used in aerial spraying in New Brunswick and most of the adult spraying was carried out with this aircraft flying in a three-plane formation carrying a total of about 7000 L of insecticide. However, in 1974 when an 800 000-ha block was treated, a four-engine DC-6B, capable of carrying 13 600 L was added to the spray fleet. The DC-6B sprayed 11 blocks, each covering 29 000 ha, while two teams of three TBM's sprayed 33 blocks, each

Table 13. Oviposition status of dead females recovered in phosphamidon plus motor stimulant and check blocks, 1977

Collection Date	Treatment		Check	
	Females examined	Percentage of eggs laid	Females examined	Percentage of eggs laid
July 8				
9			8	7
9				
10	---------SPRAY---------			
10			6	17
11			5	32
12	238	59	6	6
13			10	68
14			12	35
14	---------SPRAY---------			
15	229	68	14	66
16	60	75	9	82
17	20	74	17	83
18	59	83	64	93
19	38	86	48	88
20	62	90	31	92
21	13	97	42	93
22	15	96	21	101
23	6	94	21	99
24	11	97	27	99
25	7	90	14	96
26	5	90	3	107

covering 15 000 ha. The DC-6B flew 22 sorties and the TBM's, 79 sorties, to treat the 800 000 ha with two applications. The spraying time per sortie for both types of aircraft generally ranged from 55 to 60 min.

Counts of egg masses from sequential surveys did not show a significant difference between the DC-6B sprayed area (561 masses/10m^2) and the TBM sprayed area (490 egg masses /10m^2). However, intensive sampling on selected plots did show about a 30% reduction in the egg mass:pupa ratio in favor of the TBM (Table 14).

Impact of invading females

A major problem in any budworm control program is the probability of invasion by egg-carrying females after treatment, but we have only indirect evidence of the potential impact of this dynamic process. For example, life-table analyses (Morris and Miller 1954) suggested that over a 4-yr period invading females laid 328, 90, and 232 egg masses per 10 m^2 of foliage in one study plot in northwestern New Brunswick, during the peak of the 1949-1959 outbreak in that region. Furthermore, egg-mass counts in the same region where few budworms survived DDT larval treatments in 1952 and 1953 suggested that invading females laid 200 to 300 masses/10m^2. On the other hand, a specific study of invasion impact in 1975 suggested that invading females laid about 10 masses/10m^2 (Miller *et al.* 1978). Thus, invasion impact can be quite variable but has the potential of significantly altering budworm abundance in the invasion site.

Distinguishing invading females or eggs laid by invaders from the resident population is difficult except in instances where the resident density is close to zero and the actual number of eggs laid is far in excess of the resident potential; a reasonable assumption would then be that egg-carrying females invaded the area, but these conditions were seldom observed in our treatment blocks. Thus the impact of invasion on the 1972-1977 adult spray trials is largely unknown. In 1974, a ground- based radar was set up near the centre of the 800 000-ha spray block and airborne moth densities of over 10 000/ha were recorded on three nights in July. It is assumed that many of the moths descended into the spray block although the egg mass: pupa ratio near the radar site was 1:1 and did not suggest significant oviposition by invading females. In 1976, the maximum airborne density recorded on radar over the treatment blocks was less than 1000 moths/ha and thus it is assumed that invasion had little or no impact in that year. In 1977, moth catches in sex attractant traps, light traps in clearings, and a sudden increase in unhatched egg masses recorded late in the season all indicated a late-season moth invasion but again the impact of this invasion could not clearly be determined.

Table 14. Pupal and egg-mass counts in DC-6B and TBM sprayed blocks, 1974. (Selected plots with less than 300 resident pupae/10m^2)

Spraying system	No. of plots	Density/10^2 foliage		Ratio
		Pupae	Egg masses	Egg masses/pupa
TBM	14	166	199	1.2
DC-6B	13	163	278	1.7

ECOLOGICAL EFFECTS ON NON-TARGET ARTHROPODS IN FIR STANDS FROM ADULTICIDE TREATMENTS IN OPERATIONAL TRIAL 1972-77

THE PROBLEM

Ecologists generally agree that natural ecosystems sustain maximum stability and long-term productivity of multiple resources when normal faunal diversity and density are maintained. Therefore chemical control is suspect.

Insecticide treatments of forests to kill budworm moths in New Brunswick must take place in July when many non-target arthropods are active, reproductive, and at high abundance. Many species are thus vulnerable to dramatic population reduction, dependent upon the concentration of insecticide and frequency of spraying and their activity patterns in contaminated habitats. Vulnerable groups, important in spruce budworm dynamics, include the parasitic Hymenoptera, especially *Apanteles* spp. and *Glypta fumiferanae* (Vier.) which are present as adults in early July, and the predaceous insects, mites, and spiders which attack eggs and young larvae. More broadly, risk extends to the several faunal communities of target and non-target trees in the spruce-fir forest, to communities in the soil and litter, and to pollinators visiting the nectariferous flora. In the foliage of balsam fir, the community includes predaceous arthropods, parasitic insects (Hymenoptera, Diptera), immature and adult defoliating and sucking insects, the epiphyte browsers (Collembola, Psocidae, Acarina) and the flying insects that use conifers for transient shelter in their dispersal patterns (Diptera, Trichoptera, Ephemeroptera, Mecoptera etc).

In small-scale trials of adulticide chemicals, mortality of these arthropods can easily be demonstrated. However, the prospective long-term impact is rapidly masked by immigration of arthropods from the nearby untreated areas. Thus the larger the treatment area, the more persistent is the ecological disruption, and the more credible the research attempt to evaluate it. The problem for the researcher is first to describe the immediate impact on a broad segment of the forest fauna, then to appraise the resilience of the various ecosystems to absorb that impact and restore community balance.

METHODS

All studies were conducted in middle aged (30-60 yr) fir-spruce stands with light to moderate defoliation by spruce budworm.

Mortality of canopy insects was determined by sampling with drop-trays. Each drop-tray was a 2 m^2 polyethylene collecting surface placed beneath the crown of the tree to intercept the fall of arthropods, dead or dying from natural causes and insecticide toxicity. The vertical projection of a 2 m^2 drop tray would enclose about 5 m^2 of fir branch surface in a mature or middle-aged forest. Collections were taken daily so that the insecticide knock-down could be distinguished to some extent from the lighter, more regular fall of naturally-dying insects. The pattern of natural mortality was gauged from tallies from drop-trays in check plots of similar structure and tree cover in the same phenological zone, but remote from insecticide drift. Ten trays per treatment plot were used, scattered inside the forest rim along 100 m of access road. Such a sample plot does not representatively cover the treatment area therefore results can be used only for tentative inference of effects; conclusive proof of whole-area impact would require a representative survey.

Post-spray survival of arthropods was assessed by counting the individuals still resident in the crowns after the initial adulticide knockdown had ceased. That was accomplished by ground-spraying the cluster of trees above each drop-tray with a heavy wash of concentrated phosphamidon insecticide. There were virtually no survivors from that final wash. Collections were not extended more than three days to avoid misleading values from inflight and mortality of non-resident arthropods. The method has defects. Not all arthropods dying from insecticides tumble through the foliage to reach the tray. Excessive winds, heavy rain, and birds and small mammals may remove some of the bodies before the researcher can collect them. Some insects (syrphids, sawflies) fall naturally to the forest floor to pupate on the soil, and their presence on the tray does not necessarily indicate insecticide poisoning. Also, drop trays collect naturally-dying insects, so it is not possible to precisely separate the insecticide victims from those others.

The long-term effect on parasitism of spruce budworm (eggs, small larvae) was determined by comparison of pre-spray and post-spray values of parasitism in the same plot, or by comparisons of values in treatment and check plots, contemporaneously. The method brings only weak inference of impact and is sensitive only to gross changes.

Malaise traps, with a 2 m^2 intercepting surface on each side, were used to obtain an index of flight activity of winged insects, and thus a measure of adult survival, by comparing capture rates before and after spray and by comparing flight patterns in treatment and control plots. The malaise-trapping method also has inherent defects. Flight activity is controlled by weather variables and adult emergence patterns, while trap efficiency is affected by locality factors such as wind funnels and habitat attractants. The method also has some strengths, in that very large numbers of flying insects with extreme diversity of species are collected in a short time with a few traps. The method was satisfactorily used for testing the effects of sprays on parasitic wasps, true flies, and moths, and has much potential for sampling pollinator abundance and flight patterns.

Branch sampling for living fauna was used to test the effect of insecticides on predaceous arthropods. Samples of predators from branches of balsam fir were collected before and after spray, in both treated and check plots. Branches were cut, usually at midcrown level, beaten over a canvas, and the arthropods were collected. Since populations are dynamic, the longer the time lapse between pre- and post-spray sampling, the less valid the comparison of raw numbers to determine impact. However, the use of a check plot gives a crude measure of the natural dynamics, against which the pattern in the treated plot can be compared. The weakness of this method is that it is labor-intensive, and is most effective when a large number of sampling personnel can be applied in a short period of time. The populations of resident predator taxa (grouped by genera, families, or order) are generally at a low density; 50-100 insects per 100 m^2 of fir branch surface and spiders at 500-1000 per 100 m^2, although on occasions densities widely vary beyond these limits. In practice, it was rarely possible to muster sampling capability for more than 100 m^2 of branch surface in any one sampling effort (one plot sampled over a 2-day period).

Collectively, these field-sampling methods have serious defects:

(1) They do not adequately cover the problem of variance in faunal distributions, variance which is inherent in all ecosystems. That is, the methods have not been used as surveys to incorporate that variability, but only as point samples with a weak assumption of representativeness.

(2) The values from the sampling are the product of many population-influencing factors, both natural factors in the field, and the biases of the sampling method. Therefore, the impact of insecticide is not clearly identified; it is assumed that it is strong enough to dominate other sources of population change in short term.

(3) No attempt has been made to document the deposit of insecticide on foliage, or the persistence of residues, or the intrusion of aerosols or vapors in the air mass. The neglect of this important factor, variability of insecticide contamination of habitat, was unavoidable. The current methods of insecticide detection, foliage analysis by GLC use of tracer dyes and fluorometry, or spot-staining of Kromekote cards are expensive and not very effective in characterizing insecticide penetration of the canopy habitats. Therefore, the interpretation of change in arthropod density, without a documented cause - effect relationship, must remain suspect. Confidence in the methodology adopted must depend upon the number of replicates in any one year, or upon the number of years in which the phenomena were re-examined. On both accounts, the sampling effort is weak.

At present, field survey by these crude methods is the only known way to evaluate operational effects. While laboratory toxicology is far more sensitive, its results have only limited applicability in the field.

There is no available mathematical model that can integrate laboratory toxicology and field deposit values to arrive at a satisfactory prediction of non-target population change.

1972 Trials of phosphamidon and fenitrothion as adulticide

Drop-tray tallies indicated massive kills of adult parasitic wasps specific to budworm, and immature and adult predaceous arthropods, immediately following each of two treatments in each insecticide trial (fenitrothion (Sumithion) 2 x 140 g/ha, phosphamidon (Dimecron) 2 x 140 g/ha).

Drop-tray tallies per 10 m^2 collecting surface were:

Fenitrothion:
144 predators, 177 Ichneumonid parasites (mostly *Apanteles* spp.).

Phosphamidon:
242 predators, 344 Ichneumonid parasites.

Most of the predators were insects and there were very few spiders.

No estimates of the densities of surviving parasites and predators were made, but it was recognized, from experience in sampling seasonal densities of predators and parasites elsewhere, that the most of resident parasites and predators had been eliminated. To test the long-term effect, percent parasitisms in larval budworm populations were calculated for these plots in the following spring (1973). The values were 6% (557 hosts) in the fenitrothion plot, and 8% (204 hosts) in the phosphamidon plot. These values are low compared with the FIDS survey average

(11%) for fir stands in New Brunswick in 1973, but are well within the norms for heavily infested stands. While the impact on parasite efficacy cannot be calculated from these data, it is evident that it could not be judged as catastrophic within the plots (Miller *et al.* 1973).

1973 Trials of phosphamidon adulticides

In 1973, the objectives of the study of non-target effects were to determine the mortality of predators and parasites following various phosphamidon spray regimes and to check the survival and recuperation of parasitoids specific to spruce budworm (Varty and Titus 1974).

Four regimes were monitored: (a) 140 g/ha (b) 2 x 140 g/ha - interval 29 h (c) 35 g/ha (d) 2 x 35 g/ha - interval 4 h. Triangular drop-trays, having a surface area of 0.6 m^2 and with the apex abutted to the trunk, were placed under the tree to sample the crown spread evenly.

It was shown that the fallout of dead parasitoids was greatest on the first day after spraying (76%), decreasing through the second day (16%) to the third and fourth days (8%). All regimes killed large numbers of ichneumonoid parasitoid adults over the 4-day period, averaging as follows.

Treatment per ha	Density per m^2
140 g	128
2 x 140 g	277
35 g	207
2 x 35 g	289

These values do not indicate the rate of mortality, only the collection of dead bodies. Only in the 140 g/ha block was an estimate of total population made by use of the mistblower insecticide wash method; it was calculated that 85% of the ichneumonoid population was killed in the 4-day period, but this includes both insecticidal and natural mortality.

This heavy knockdown of ovipositing adult parasitoids did not appear to have adverse effects on percent parasitism of spruce budworm larvae, as monitored:-

Treatment block	% parasitism (*Apanteles, Glypta*) 1973 pre-spray	1974 post-spray
140 g	17.5	22.2
2 x 140 g	17.5	22.1

However, in the year following spray, parasitism by *Glypta* had substantially increased over the pre-spray percentage, while that of *Apanteles* had diminished. It is not known whether insecticide usage interferes with the competition between *Apanteles* spp. and *Glypta fumiferanae* for the same host population.

Predaceous arthropod populations were subject to moderate to severe mortality from the various spray regimes; the sequence of knockdown averaged 72% on the first day, 16% on the second, and 12% on the third and fourth days. The most frequent victims were mirids, ladybeetles, spiders, and other beetles, but the relative potencies of the four regimes were not investigated. The 140 g/ha treatment apparently killed about one-quarter of the total number of predators in sampled trees, but it was believed that spray deposit in this plot was lower than expected (low kill of budworm moths).

The drop-tray data indicate extensive kill of other arthropods - hundreds of species and at least 15 orders. About one-third of the dead insects were winged transients not directly dependent upon the spruce-fir canopy. They included insects from soil, stream, dead vegetation and the shrub-herb layer, indicating that the impact of sprays reached every ecological niche in the forest.

1974: Large-scale trials with phosphamidon

Earlier research on efficacy of insecticides against spruce budworm adults had indicated that the favored regime was phosphamidon applied at 70 g/ha in two applications at 2-3 day intervals. The most urgent problem in side effects was to determine the impact on parasites. The area of the trial (800 000 ha) was large enough to eliminate the problem of post-spray immigrant redistribution of flying adult parasites which masks the influence of local knockdown in small-scale trials. A secondary objective was to document the effect of the insecticide on other flying insects. Sampling was conducted in an untreated check plot at Renous and in treated plots at Renous and Trout Brook in central New Brunswick. The insecticides were applied as two (three in a few selected blocks) sprays in mid July. The treated lots included some which had earlier larvicide applications (L + A) and some with adulticide treatments only (A).

Ichneumonoid parasite mortality

Ichneumonoid parasites in spruce-fir stands comprise scores of species interacting with hundreds of host species. However, about 76% of all inchneumonoid wasps collected on drop trays were *Apanteles* spp., and subsampling indicated that most of these were *Apanteles fumiferanae*. Thus, at least half the specimens collected were prospective biological control agents for spruce budworm.

The results of drop-tray counts of ichneumonoid adult parasites in the 11-day post-spray surveillance period are shown on Table 15. The rate of survival in the check plot was about 10 times greater than in the treated plots. Natural mortality in the check plot during the spray period, 14-24 July, was 58.5%, and presumably a similar natural mortality factor was applicable in the treated plots. Thus, in the treated plots spray-induced mortality was no doubt substantially lower than the total mortality shown in Table 15. Nevertheless the adulticide treatments undoubtedly caused a drastic reduction in the inventory of parasite adults; a reduction in rates of parasitism was a reasonable hypothesis and was thus investigated further.

Budworm parasitism

To test the effect of kill of adult parasites of small budworm larvae, budworm hosts were sampled and dissected to determine rates of parasitism before (April 1974) and after treatments (April 1975) in the Renous and Trout Brook sample plots (Table 16). Each of the five population samples was about 200 second-instar larvae. All plots produced

Table 15. Drop-tray collections of ichneumonoid adult wasps under balsam fir and spruce canopy in the Renous plots, 1974

Plot (Renous)	No. of adulticide sprays	No. of ichneumons per 10 m^2 drop-tray surface: Cadavres 14-24 July	Surviving 25 July	% survival
L + A	3	333	13	3.8
A	2	365	21	5.4
Check	0	110	78	41.5

Table 16. Percent parasitisms *(Apanteles* spp., *Glypta fumiferanae)* in overwintering spruce budworm larval populations, before and after adulticide treatments in July 1974

	April 1974	April 1975
Renous L + A	8.6	13.3
Renous A	7.6	9.1
Trout Brook L + A	14.0	16.3
Trout Brook A	15.8	18.0
Renous Check	18.0	13.8

pre-spray percent parasitisms within the norms (based on provincial monitoring experience). The check plot had the highest parasitism initially, but it declined naturally during the test year. Curiously, percent parasitisms increased in all the treated plots. It seems possible therefore, that the adulticide treatments may have been relatively more powerful in depressing the host populations of small budworm larvae than in depressing parasite host-finding and reproduction. The conclusion is that while adulticides killed a large proportion of adult parasites, they did not damage the function of parasitism.

Egg parasitism

The egg parasite *Trichogramma minutum* Riley is another potential indicator of stress in the ecosystem. This small wasp parasitizes eggs of many species and is believed to have three generations in New Brunswick. As an adult in July, it seeks out budworm egg-masses, generally attacking 5-25% of the masses. Adults could be vulnerable to adulticide chemicals through flight interception of aerosols or by dermal contact with deposits on foliage. Egg parasitism is a statement of relationship between parasite population and egg-mass population. It is difficult to interpret any change in values, whether between years, or between treatment and check plots in the same year, because both parasite and host source are subject to many factors affecting population, including the insecticide. However it would be reasonable to expect percent parasitism to decline, on average, if the insecticide were markedly and differentially more lethal to the parasite.

An exploratory sampling of egg masses from July 23 to 29 in the three Renous plots produced tentative evidence of deleterious effects:-

Plot	% Parasitism	No. of egg masses examined
L+A	1.8	263
L+A	2.1	142
Check	6.3	457

Note that the average percent parasitism of budworm egg-masses recorded in the FIDS tally from 1100 plots in New Brunswick in 1974 (E.G. Kettela, Pers. Comm.) was 6.5% in larvicide sprayed areas and 7% in unsprayed areas. Further investigation of adulticide effects on egg parasitism is necessary.

Flying insect survival

Flying insects are susceptible to insecticides through wing contact with aerosols or vapors and perching contact with deposits. Malaise traps were used to obtain an index of population survival, by comparing catches in treated and check plots over the spray period. The results (Table 17) show that adulticides caused broad-spectrum reduction of flying insects, thus complementing the more habitatrestrictive evidence from drop-trays. The check plot data (Table 17) can be considered as the population norm for flying insects susceptible to trapping in fir-spruce forest undisturbed by insecticide, with the caveat that no one-plot can be representative of densities and distributions of the winged insect fauna in the spruce-fir forest at large. However, it can be reasonably inferred that insect abundance in the treated plots was reduced by two- thirds or more; it is further suggested that the successive phosphamidon sprays had a devastating effect on populations of *Apanteles* parasites, sawflies, and wild bees. This inference is based on the assumption that all three sites would produce similar quantities of flying insects, many of them itinerants dispersing from afar. In fact, however, the pre-spray samples indicate that the check plot tended to be naturally richer in both species diversity and population densities of predators and parasites, so the comparison of catches among the three plots may somewhat exaggerate the supposed impact.

1976: Comparison of aminocarb and phosphamidon as adulticides

Non-target arthropods in the small-scale adulticide trials in 1976 were monitored to compare the effects of aminocarb (Matacil) and phosphamidon. Phosphamidon was applied at three applications of 70 g a.i./ha in a 240-ha block, and aminocarb was applied twice at 70 g a.i./ha.

Drop-tray studies of arthropod mortality

In each of three plots (L+A, A and Check) daily collections from 10 drop-trays were made in the 11-day period 5-15 July, beginning with the first spray and concluding 6 days after the third spray, to docu- ment the impact of the adulticide treatment. The rate of survival was measured by mist-blowing the survivors (with a heavy wash of phosphamidon) and recovering their bodies from the same trays, 16th-19th July.

The tallies of dead arthropods (Table 18) showed that both insecticides were lethal to a broad spectrum of arthropods. The phosphamidon

Table 17. Total numbers of insects caught in Malaise traps in the Renous plots July 10-26, 1974

Taxon	L+A	A	Check
Choristoneura fumiferana	97	132	1575
Itame pustularia	384	248	285
Other Lepidoptera	81	125	409
Homoptera	129	158	492
Psocoptera	4	122	238
Coleoptera	185	326	511
Total Hymenoptera	511	971	6950
Apanteles spp.	(23)	(60)	(1607)
Glypta spp.	(-)	(5)	(32)
Apoidea	(8)	(5)	(77)
Tenthredinidae	(5)	(6)	(164)
Diptera	6989	9441	29225
Other orders	6	33	93
Grand total	8386	11556	39778

regime apparently killed more predaceous insects (mostly hemipterous bugs) and transient flying adults (flies, mayflies, caddisflies), but it should be recalled that three sprays of phosphamidon were used, and only two of aminocarb. Aminocarb apparently killed more spiders, adult hymenopterous parasites, and the browsing/sucking insects. However, the performances of the two regimes with regard to non-target insects were similar. The only truly drastic effects were the apparently high rate of mortality of spiders, and the 90% kill of *Apanteles* adults by the aminocarb regime.

Note that considerable natural mortality took place contemporaneously with the spray period in the check plot. Thus, for example, the 46% survival of parasitic Hymenoptera in the phosphamidon plot compares with 24% in the aminocarb plot, and 77% in the check. In effect, not all of the mortality experienced in treated plots can be attributed to insecticide.

Survival of predaceous arthropods in the fir canopy

Arthropods were sampled from the lower crown of fir trees in phosphamidon and aminocarb treatment plots and in a check plot, pre-and post-adulticide treatment, to determine effects of insecticide on predator density (Table 19). In each plot, 100 m^2 of foliage were beaten over a canvas and predators were collected for identification and tally. Pre-spray samples were taken on June 25-28, the plots were sprayed July 4-10, and post-spray samples were taken on July 20-22. The tallies in the check plot indicate the expected population trend, against which change in the treatment plots can be compared (Table 19). There was no indication of drastic reductions following aminocarb spraying.

1977 Effect of successive sprays against non-target arthropods

In 1977, the monitoring objective was to determine the impact of each of the sprays on non-target arthropods, including their cumulative population effect on survival.

Nineteen drop-trays (38 m^2 collecting surface) were placed beneath fir trees, and the drop of insects was tallied daily for eight days from the onset of spraying (Table 20). Table 20 shows the numerical dominance of Lepidoptera on the arthropod populations of balsam fir crowns in July; 94% of these were spruce budworm. There was a corresponding abundance of dipterous and ichneumonoid parasites associated with budworm. However, whereas most adult parasitic wasps were killed by the insecticide, the fate of the dipterous parasites is less certain. In mid July mature dipterous larvae emerge from the pupal budworm hosts and either form a puparium in the foliage or drop to the litter to pupate. The proportion making lethal contact with insecticide residues is unknown.

Table 20 also shows a remarkably low fall-out of spiders. The rate of collection (9/10m^2 drop-tray) over the 8 day period is only about 10% of the expected spider density in fir canopy. The retention of dead or live spiders in the foliage was not deliberately checked in the drop-tray sampling, but this was investigated by branch sampling for predators in the associated experiment in an adjacent plot.

Table 21 shows the cumulative rate of kill, by each of the three sprays based on collections of cadavres during the 3-day, 2-day and 3-day periods after sprays 1, 2, and 3, respectively. The apparent kill of non-target arthropods was about 90%, based in the drop-tray collections. All three sprays (at 70 g a.i./ha)

Table 18. Mortality and survival of arthropods on fir in two spray regimes and a check plot area during an 11-day period following first application of insecticide; July 1976 (drop-tray method - densities per 10 m^2 collecting surface)

Taxon	Phosphamidon*			Aminocarb*			Check		
	Dead	Live	% surviving	Dead	Live	% surviving	Dead	Live	% surviving
Budworm adults	276	0	0	79	0	0	159	28	15
Other Lepidoptera	71	18	20	91	10	10	44	73	62
Coleoptera	51	6	11	29	12	29	10	15	60
Predaceous insects	15	9	37	11	10	50	4	20	83
Spiders	25	30	55	16	1	6	4	14	78
Parasitic Hymenoptera	100	85	46	102	33	24	25	86	77
Browsing/sucking Insects	15	40	73	21	24	53	13	58	82
Transient insects	481		11	75	31	29	104	140	57

*
Aminocarb sprays at 70 g a.i./ha: 5 and 7 July.
Phosphamidon sprays at 70 g a.i./ha : 4, 6, and 9 July.

Table 19. Numbers of predatory arthropods per 100 m^2 of balsam fir foliage, pre-spray and post-spray, in stands treated with insecticide or untreated (branch beating method)

	Phosphamidon		Aminocarb		Check	
	Pre-spray	Post-spray	Pre-spray	Post-spray	Pre-spray	Post-spray
Mirids	32	11	36	37	33	39
Nabids	2	4	-	1	-	4
Pentatomids	1	-	-	-	-	-
Reduviids	-	-	-	1	-	2
Hemerobiids	-	-	-	1	-	-
Elaterids	5	1	11	7	8	4
Staphylinids	10	1	18	1	4	-
Lampyrids	-	-	1	-	-	-
Carabids	-	-	-	-	1	-
Formicids	3	2	4	3	6	2
Pred-mites	6	13	21	66	1	31
Phalangids	13	4	8	-	6	3
Araneids	484	468	610	824	328	781

Table 20. Fir-dependent arthropods/10 m^2 drop tray collected daily, adulticide spray trials at Heath Steele, July 12-19, 1977

July	12	13	14	15	16	17	18	Total (12-18)	19 (wash)
Collembola	-	-	<1	<1	<1	-	-	1	-
Psocoptera	1	<1	<1	-	<1	1	<1	4	<1
Thysanoptera	-	-	<1	-	1	<1	-	1	-
Hemiptera	<1	<1	1	3	2	1	<1	10	1
Homoptera	4	1	2	4	2	6	2	21	1
Coleoptera	7	3	4	7	2	3	2	28	3
Neuroptera	<1	-	<1	1	1	1	-	5	<1
Lepidoptera	121	115	136	243	164	303	189	1271	94
Diptera (parasitic)	9	10	7	9	7	6	3	51	1
Diptera (syrphids)	6	1	1	2	1	2	<1	14	1
Apanteles spp.	20	6	13	40	36	35	8	158	18
Glypta spp.	<1	-	-	<1	2	2	-	6	4
Other Ichneumonoidea	8	1	3	8	7	14	2	43	3
Acarina (predatory)	1	1	1	<1	-	<1	<1	6	<1
Araneida (spiders)	<1	-	-	2	<1	5	<1	9	<1

Note: Aerial spray (phosphamidon) was applied July 11, 14, 16.
Ground-based misting (phosphamidon wash) was applied July 18.

contributed more or less evenly to this total attrition. It is therefore suggested that prospective damage to ecological processes increases with the number of sprays, and that more than three treatments might cause serious problems of population recuperation by resident arthropods.

Sampling of predaceous arthropods

Fir foliage from the sprayed stand was sampled to determine densities of living predaceous arthropods before and after the three phosphamidon spray treatments. Samples were taken on July 10 (pre-spray) and July 17 (post-spray), by cutting two branches from each of 50 trees, on each date, totalling about 22 m^2 of branch surface. Densities of predaceous arthropods (by order) are shown in Table 22. Assuming that predator density would remain the same over the 7-day period in an undisturbed habitat, it may be inferred that the difference between pre-spray and post-spray densities is attributable to insecticides; the total population was reduced by 46%, and the spider population by 29%.

Table 21. Accumulative percentage kill of total population of the taxon, from drop-tray collections in adulticide spray trials, Heath Steele, July 12-19, 1977

	Spray 1	Spray 2	Spray 3
Hemiptera	40	56	88
Coleoptera	46	68	91
Neuroptera	19	43	90
Budworm moths	26	45	95
Lepidoptera total	27	45	93
Apanteles	22	45	90
Ichneumonoidea total	22	43	89

Table 22. Population density of living predaceous arthropods per 100 m^2 foliage surface (balsam fir) in adulticide treatment plot, Heath Steele (branch beating method)

	Pre-spray (July 10)	Post-spray (July 17)
Hemiptera	260	105
Coleoptera	73	5
Neuroptera	5	-
Acarina (predatory)	210	-
Phalangida	18	9
Araneida	1055	750
Totals	1621	869

Those estimates must be interpreted with caution because of the small sample size. From each lot of 22 m^2 of foliage, the actual numbers of arthropods tallied were:-

(1) pre-spray :	57	Hemiptera
	16	Coleoptera
	1	Neuroptera
	44	Acarina
	4	Phalangida
	231	Araneida
(2) post-spray :	23	Hemiptera
	1	Coleoptera
	2	Phalangida
	164	Araneida

The densities of beetles, lacewings, and harvestmen were apparently so low that chance distribution may govern the estimates, and it is unwise to hazard an inference about their responses to insecticide. To interpret the effect on the hemipterous bugs, mites, and spiders, it would be necessary to check the assumption of population stability for a 7-day period in mid July. Experience, elsewhere, in monitoring the seasonal responses of the fir dwelling community suggests that acarine and spider populations are stable in mid July, and bug populations are slowly declining. Therefore, the sharp decline between pre-spray and post-spray sample is probably attributable to the treatment.

The estimates of density by the two methods (drop-tray, branch-beating) are related to the same population universe and can be crudely compared. Assuming that the vertical projection of 1 m^2 of ground surface corresponds to about 5 m^2 of overhead branch surface, then double the densities in Table 20, and the densities shown in Table 22 should give roughly similar estimates, provided the two adjacent plots had similar population distributions and similar methodological efficiencies. The comparison of those two tables shows a large discrepancy in estimates of Araneida, Acarina, and Hemiptera.

This discrepancy may be attributable, in part, to variance within plots and to variation between plots, or to the extraction efficiency of free fall of cadavres to drop-trays versus beating live arthropods to canvas. However, based on past experience, the branch-beating method gives a credible estimate of density. Therefore, particularly in relation to spiders, it is believed that the drop-tray technique may produce a serious underestimate of density. It seems reasonable to hypothesize that spiders do not drop freely to the ground when afflicted by insecticide poisoning, but perhaps retreat to their inner sanctuaries. Cadavres would then be retained on the foliage.

DISCUSSION

The effects of insecticidal regimes (for budworm moth control) on non-target arthropods were studied from 1972-1977. Over the years, the operational trials tested several of insecticides, concentrations, and frequencies of application in diverse spruce-fir stands in the province of New Brunswick. Environmental monitoring of the immediate and short-term responses of non-target arthropods during the 1972-1977 adulticide trials produced evidence of heavy knockdown of many kinds of tree-dwelling and flying arthropods when insecticides were applied repeatedly to spruce-fir forest in mid July. Phosphamidon, fenitrothion, and aminocarb regimes all produced roughly equivalent kill of non-target arthropods. Among the most vulnerable were the ichneumonoid adult parasites (*Apanteles* spp., *Glypta fumiferanae)* which attack small budworm larvae.

However, most of the evidence suggests that the function of parasitism in budworm dynamics was not damaged, except possibly egg parasitism. Spiders appeared to be less vulnerable to these insecticide regimes, but more definitive assessment of the available sampling methods is still required. Populations of predatory insects and mites appeared to be highly vulnerable and susceptible to light dosage treatments. Kill of all kinds of arthropods is strongly related to the frequency of treatments, so each additional spray markedly reduces survival of populations of predaceous arthropods. However, the risks from adulticide treatments cannot yet be assessed in terms of community resilience.

In addition, there are many direct problems associated with the use of chemical insecticides to kill budworm adults and suppress a population.

(1) Invasion of egg-carrying females into a treated area (a probability in any budworm-prone forest selected for any type of control).

(2) The need, in theory, to treat a population many times in a 10-day period to successfully reach daily emerging adults.

(3) The probability that unfavorable weather might disrupt spraying operations during the relatively short 'spray window'.

(4) The inability, with treatments tested to date, to kill young females that have laid few eggs.

(5) The lack of spray formulation and technology data pertinent to adults.

In spite of limitations, we learned that a 50 to 60% reduction in egg- mass densities could be achieved when large blocks were treated twice with 140 g phosphamidon per hectare but results were disappointing when small blocks of less than 1000 ha were treated three times with 70 g phosphamidon per hectare per treatment.

The most consistent result observed in all tests was that a dosage rate of 70 g phosphamidon per hectare can either kill or disrupt the behavior of 70% or more of the males in a population. The same dosage appears to be reasonably effective in killing the older females (for example, invaders) carrying up to 50% of their eggs.

The realization that young females were not vulnerable came late in our testing program which was primarily aimed at killing resident females. Only one test was specifically aimed at males in an attempt to disrupt mating and this test showed promise in that 41% of the female population died as virgins. There is little doubt that an early spraying test to kill males should be continued and possibly expanded to determine the level of success that could be achieved with four applications during the male emergence period. Tests should also be conducted on dosage rates necessary to kill males, which may be comparatively low.

Thomas *et al.* (1979) suggested that a pheromone treatment be incorporated with an adulticide. The assumption is that the pheromone could be used to disrupt mating when few moths were present early in the emergence period. Once a significant number had emerged, one or two adulticide treatments could then be used to decimate the male population.

It would appear that as an overall strategy in population control the greatest success in spraying moths could be achieved early in an outbreak before local eruptions (as delineated by defoliation) coalesced into a major epidemic. Early sprays to kill males could disrupt mating as well as kill mated females capable of dispersing into downwind sites. Such a tactic might minimize the explosive characteristic of a budworm outbreak and "buy" time in which to plan a protection program appropriate to the socio-economic values of the area under attack.

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