SEX PHEROMONE TRAPS FOR MONITORING SPRUCE BUDWORM POPULATIONS: RESOLVING OPERATIONAL PROBLEMS

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ABSTRACT

Sex pheromone traps are now used for monitoring populations of spruce budworm (*Choristoneura fumiferana* [Clem.]) at more than 500 locations annually across eastern North America. This report describes experiments that have been carried out during the development of this program during the 1985–1991 period. These experiments have resulted in standardization of the trap and lure, and in trap deployment. Problems of contamination of the traps by pheromone and of inconsistensies in the potency of the lures from year to year have been identified. Cheaper, disposable traps would solve potential contamination problems and would also avoid the inconvenience of cleaning and storing traps. Inconsistencies among lures can be minimized by stockpiling pheromone of known purity for use in the manufacture of lures each year. To safeguard against inconsistencies, each new batch of lures should be cross-calibrated against the previous batch.

RÉSUMÉ

Les pièges à phéromone sont maintenant utilisés pour surveiller les fluctuations annuelles des populations de la tordeuse des bourgeons de l'épinette (*Choristoneura fumiferana* [Clem.]) dans plus de 500 endroits répartis dans l'est de l'Amérique du Nord. Le présent rapport décrit les essais menés au cours de ce programme, pendant la période 1985–1991. Ces essais ont permis de normaliser le piège et l'appât et les méthodes de déploiement sur le terrain. On a identifié certains problèmes de contamination des pièges par la phéromone ainsi que de variation de l'efficacité des appâts d'une année à l'autre. Des pièges jetables et moins coûteux pourraient réduire le problème de contamination et élimineraient l'étape du nettoyage et l'entreposage. On peut minimiser le problème des appâts en accumulant des réserves de phéromone de pureté reconnue qui serviront à faire les appâts chaque année. Par souci d'uniformité, il faudra analyser chaque nouveau lot d'appâts préparé et le comparer au lot précédent.

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INTRODUCTION

The development of a spruce budworm (*Choristoneura fumiferana* [Clem.]) monitoring program using sex pheromone traps began in 1971, after the identification of the major pheromone component, *E*–11–tetradecenal (Weatherston et al. 1971). Initial results were inconsistent, and it was subsequently discovered that the pheromone consists of two major components, *E*– and Z–11–tetradecenal in a 95:5 ratio. Early work centered on the use of sticky traps, but later switched to "non-saturating", high-capacity traps. The monitoring program received considerable impetus during the Canada–United States (CANUSA) Spruce Budworms Program (1977 to 1984), culminating in 1985 with a coordinated trapping program that covered the economic range of the spruce budworm in eastern North America. From the beginning, it was emphasized that the main goal of the program was to monitor changes in population density from year to year, which would give an early warning of impending outbreaks; for this, only an index of population change is required. The more ambitious goal of providing quantitative estimates of absolute population density to supplement or replace existing sampling techniques such as egg-mass or L^2 sampling was a secondary objective, which would be evaluated as the program developed.

During the course of the program since its inception in 1985, a number of problems that affect the use of the traps and the interpretation of the results have arisen, and these have been the subject of an ongoing research program. This report outlines the results of this research through 1991. The analysis and interpretation of the results will be the subject of a subsequent report.

PROTOCOLS

The program has been closely coordinated throughout, and a standardized protocol has been adopted (Allen et al. 1986a). The Multi-pher-I plastic canister trap (Le Groupe Biocontrôle, Ste–Foy, Québec), which contains a resin strip impregnated with dichlorvos to kill the trapped moths, was recommended. The recommended lure was initially a polyvinyl-chloride (PVC) pellet, 4 mm in diameter by 10 mm long, that contained 0.03% (w/w) of the attractant, a 95:5 blend of *E*:*Z*–11–tetradecenal. For reasons outlined below, the program switched to using Biolures (Consep Membrane Inc., Bend, OR) in 1989. Each trap is attached to a branch about 2 m above the ground, at least 0.5 m from live foliage. A triangular cluster of three traps is recommended, with approximately 40 m between traps, and all traps should be within the stand, at least 40 m from the edges. Ideally, traps should be deployed when larvae begin to pupate and traps are left undisturbed until flight activity ceases, 5 to 6 weeks later.

The numbers of trapping locations in each year and their locations are summarized in Table 1. The distribution of traps and lures during each year is shown in Table 2. Traps were purchased directly from Le Groupe Biocontrôle for the first year of the program and have been supplemented each year as necessary. Because of concerns about contamination of the traps by the pheromone (see below), which could result in the traps themselves being attractive from one year to the next, recommendations were made that the traps should be washed in detergent after use and left in the sun for a day or two to remove and/or degrade the pheromone. For the same reason it was also recommended that traps should be used for trapping only the same insect species in successive years. The PVC lures were manufactured by the New Brunswick Research and Productivity Council (RPC), which supplied the pheromone itself. Those for use in the U.S. were sent directly to the USDA Forest Service, State and Private Forestry, Durham, N.H. Those for use by the Québec Ministère de l'energie et des ressources (PQ MER) were sent directly to PQ MER. The remainder were sent for distribution to C.J. Sanders (Forestry Canada, Sault Ste. Marie, Ont.). In some years, because of the large numbers involved, the lures had to be manufactured in several batches. Records were kept of which batch was sent to which user. Samples of lures from each year were kept by RPC for analysis of the release rates, and in 1986 a sample was also analyzed by E. Meighen of McGill University in Montreal. Vaportape II insecticide strips were obtained each year from the manufacturer (Health–Chem Corp., New York, N.Y.). Those for use in the U.S. were distributed by D. Souto, (USDA Forest Service, State and Private Forestry, Durham, N.H.), those in Canada by C.J. Sanders. The Biolures were manufactured by Consep Membrane Inc. In 1989, the pheromone was obtained from RPC, in 1990 from Orsynex Inc. (Columbus, OH), and in 1991 from G.E. Daterman (USDA Forest Service, Corvallis, OR). Throughout this paper, PVC lures and Biolures will be referred to by the year in which they were manufactured, e.g., PVC–88 and Biolure–88 for lures manufactured in 1988. Unless otherwise specified, the PVC lures contained 0.03% (w/w) of the pheromone blend. The Biolures are the Consep Membrane Inc. C–type.

Table 1. Number of spruce budworm monitoring plots (sex pheromone traps), 1985–1991, by province or state.

Location/Cooperator	1985	1986	1987	1988	1989	1990	1991
Canada							
Newfoundland	15	40	47	50	50	49	50
Prince Edward Island	1	1	1	1	1	1	1
Nova Scotia/Forest Insect and Disease Survey	6	6	6	6	6	6	6
Department of Lands and Forests	5	5	5	2	0	0	0
New Brunswick/Forest Insect and Disease Survey	3	3	3	3	3	3	11
Forestry Canada Research	10	10	10	10	0	0	0
J.D. Irving Company	5	5	4	2	2	14	17
Department of Natural Resources and Energy	10	9	10	10	0	0	0
Quebec/Ministère de l'energie et des ressources	166	317	287	264	270	250	272
Ontario/Forest Insect and Disease Survey	30	50	56	56	33[a]	52	62
Research	0	1	22	19	22[b]	22	23
United States							
Maine/USDA Forest Service, State and Private Forestry	35	37	40	33	33	17	17
USDA Forest Service Research	20	14	12	12	0	0	0
Maine Forest Service	76	99	169	240	103	20	0
International Paper Company	15	39	24	22	21	0	0
New York	24	24	40	40	40	40	40
Vermont	25	26	25	26	26	26	25
New Hampshire	24	18	23	22	7	7	7
Minnesota	23	37	32	26	12	7	3
Michigan	0	6	4	6	6	4	0

[a] Includes 32 locations with both PVC-baited traps and unbaited traps.

[b] Includes 22 locations with both PVC-baited traps and unbaited traps.

Table 2. Allocation of pheromone lures (1986–1991), showing the numbers received by the principal distributors and the batch code, in parentheses.

	1986	1987	1988		1989		1990	1991
Location/distributor	PVC 0.03%	PVC 0.03%	PVC 0.03%	PVC 3.0%	PVC 0.03%	Biolure	Biolure	Biolure
Newfoundland/Raske	250 (C)	250 (C)	200 (C)	0	30	150	150	160
Maritimes/Magasi	130 (B)	125 (E)	120 (C)	0	0	42	100	158
Thomas	–	–	50 (F)	–	–	–	–	–
Quebec/Jobin	200 (B)	100 (E)	200 (–)	160	75	200	200	200
Auger	950 (A)	1,000	1,000 (A,B)	0	100	1,000	1,500	900
	100 (C)	–	–	–	–	–	–	–
Ontario/Howse	150 (C)	200 (D)	200 (B)	10	150	225	198	170
Sanders	–	–	–	–	–	–	300	300
Prairies/Cerezke	400 (C)	125 (E)	150 (B,C)	0	0	100	100	150[a]
Grandmaison	–	–	–	–	0	50	–	–
Henderson (AL)	–	–	–	–	–	–	–	120[a]
Walter (Sask)	–	–	–	–	–	–	–	300[a]
City of Edmonton/ Saunders	60 (B)	30 (E)	30 (C)	–	40	0	30	35[a]
U.S.A./Souto	1,500 (A,B,C)	–	2,000 (–)	200	–	–	700	600
Trial	–	–	–	–	260	550	–	–

[a] At this location, Biolure–90 was used in 1991.

Each year, experiments were carried out in support of this program to resolve problems as they occurred, and the users and the researchers have met annually in order to discuss the progress of the program, to identify and attempt to solve problems, and to improve the effectiveness of the program. Results up to and including 1985 have already been published (Sanders 1978, 1979, 1981a, 1981b, 1984b, 1985, 1986a, 1988; Sanders and Meighen 1987; Allen et al. 1986b). The present report summarizes the results and conclusions from these earlier reports, and reviews experiments carried out from 1987 through 1991. It therefore serves to bring together in one publication information concerning the program that may be of importance in the interpretation of the operational monitoring program.

EXPERIMENTS AND RESULTS

Experimental Sites

The experiments described in this report were carried out in Ontario, mostly at one of two sites. The first, referred to as Kirkwood, is a 40-ha, 60-year-old white spruce (*Picea glauca* [Moench] Voss) plantation, 10 km north of Thessalon and about 90 km east of Sault Ste. Marie. The last spruce budworm population in this area collapsed in 1981. Since then, populations have remained low (<1 late-instar larva per branch). The second area is near Black Sturgeon Lake, 70 km north of Nipigon, in northwestern Ontario. This site has been the study area for investigations of spruce budworm population dynamics for many years. It comprises a boreal mixedwood forest, originating from a spruce budworm infestation in the 1940s and 1950s. The characteristics of the site have been descibed by Lethiecq and Régnière (1988). Spruce budworm populations increased to infestation levels in 1983 and levels have remained high through 1991.

Pheromone Blend

The major components of the sex pheromone are a 95:5 blend of *E*:Z–11–tetradecenal (Sanders and Weatherston 1976, Silk et al. 1980). Traps baited with PVC pellets incorporating this blend at appropriate concentrations catch as many male moths as a trap baited with a virgin female moth (Sanders 1981a,b; see also Fig. 15). Laboratory experiments, however, have shown that when the 95:5 blend of *E*:Z–11–tetradecenal is released at the same rate as the pheromone is released by a virgin female moth, it is not as potent as the female-produced pheromone (Alford et al. 1983, Sanders 1984a). This has led to the conclusion that the female-produced pheromone contains additional minor components; although considerable effort has gone into their identification, none have so far been identified that raise the potency of the blend to equal that of a virgin female (Silk and Kuenen 1986, Sanders 1990a). In spite of this, the 95:5 blend alone is a very effective attractant. Significant numbers of male moths can be attracted and captured even at the lowest population densities. It is therefore quite suitable for use as a lure in a monitoring program. If a more potent blend is subsequently identified, then the concentration of the lures could be changed to maintain the same rate of capture, and catches with the old and the new blends can be cross-calibrated by placing traps baited with either the old or the new blend simultaneously at the same location.

Trap Design

Initially, monitoring was carried out with sticky traps, and comparative tests identified the Pherocon 1CP trap as the trap of choice (Sanders 1978). However, because these traps become saturated after only about 50 male budworm moths have been captured (Houseweart et al. 1981), the range of population densities over which they are of use is limited. Attention therefore switched to so-called "high-capacity, non-saturating" traps. These differ from sticky traps in utilizing some form of bucket that can hold many thousands of moths, which are immobilized and killed by an insecticide inside the bucket. Various home-made trap designs were tried at first (Ramaswamy and Cardé 1982, Sanders 1984b), and the results indicated the potential for these types of trap (Ramaswamy et al. 1983; Sanders 1985). Subsequently, commercial designs came on the market. Sanders (1988) evaluated five of these and concluded that the best for monitoring spruce budworm populations were the Unitrap, manufactured by International Pheromone Systems (IPS, Wirral, U.K.) or the Multi-pher trap designed by Jobin (1985) and manufactured under licence by Le Groupe Biocontrôle. The Multi-pher trap has been chosen because it is manufactured in Canada and because the patent is held by the Government of Canada, which facts should increase the probability of an assured, long-term supply.

Some users have complained of the extra work load involved in washing the traps after use. The traps also require a considerable amount of space for storage during the 10 months or more that they are not in use. These concerns, coupled with concerns about contamination of the traps by pheromone used in them in previous years (see below), point to the desirability of a cheaper, biodegradable trap that can be disposed of after a single usage.

Trap Deployment

Height of traps

Miller and McDougall (1973) were the first to show that catches of male spruce budworm moths in pheromone traps increase with increasing height within the stand, and Sanders (1981a) subsequently showed that this is a function of the amount of foliage rather than height alone (Table 3). As a result, inter-trap variance for crown-level traps is considerably less than for ground-level traps (Miller and McDougall 1973). It is possible to place traps in the canopy by using some device such as a pole with a forked end to raise the trap to the required height. However, this is inconvenient and it is likely to present more problems, such as standardisation of placement and exposure to sun, rain and wind, than it would solve; thus, the decision was made to place traps at head height for practical reasons. For monitoring purposes, striving for maximum catches is unnecessary, because the prime objective is to obtain a consistent index of population density, and for this, catches in ground-level traps baited with lures at a potency similar to that of a calling virgin female moth are adequate.

Distance between traps

Traps should ideally be deployed far enough apart to avoid competition between traps. The required distance depends on the effective attractant distance of a trap,

Table 3. Catches of male spruce budworm moths in female-baited traps at different heights in the canopy at Black Sturgeon Lake. Overmature stand = scattered white spruce 25 m tall, understory 10 m tall; immature stand = 10 m tall. Note: maximum catches occur under a continuous canopy (from Sanders 1981a).

	Trap height (m)	Year				
		1965	1966	1967	1968	Total
Overmature stand	24	9	34	36	20	99
	17	32	83	32	51	198
	10	51	54	59	72	236
	3	59	72	56	40	227
Immature stand	9.5	–	–	63	14	77
	7	–	–	60	15	75
	4.5	–	–	39	11	50
	2	–	–	23	21	44

which in turn depends upon the potency of the lure, wind speed, humidity, etc., and is difficult to determine. Even in mark-and-release experiments, it is virtually impossible to determine when a moth switches from upwind "searching flight" (before it has perceived pheromone) to "oriented flight" after it has perceived the pheromone. Estimates of the attractant distance of traps can be made from the catches in a grid of traps. Calculations are based on the assumption that the peripheral traps catch more moths than the interior traps and that the extra catch is proportional to the additional area over which moths are attracted and captured by these traps. Thus, in a 40- x 40-m grid, the catch in each interior trap represents a trapping area of 1,600 m^2. Dividing the catch by 1,600 then gives the catch per square metre. The additional catch in the peripheral traps can then be used to calculate the additional area from which moths are being drawn around the periphery of the grid. Dividing this by the outside dimension of the grid then provides an estimate of the additional distance over which the moths are attracted.

In 1988, a 7 x 7 grid of Multi-pher traps, spaced 40 m apart and baited with PVC–88 (see below), was set up at Black Sturgeon Lake (during the fifth year of the outbreak). All 49 traps and locations were numbered. Each day, all traps were removed, their contents counted, and the traps redeployed in a different, random sequence. This was repeated four times, so that each trap was positioned at five random locations during the course of the experiment. Traps at the 25 inner locations captured an average of 283.0 ± 103.0 moths per trap. This represents 0.177 moths for each square metre of the 40- x 40-m area surrounding each inner trap. The peripheral 24 traps averaged 294.1 ± 71.6 moths per trap. These catches were not significantly different. However, if we accept that the difference of 11.1 moths is real, then this number equates to an additional trapping area of only 62.76 m^2 per trap, or a total of 1,506.24 m^2 for all the peripheral traps around the grid. The additional distance of attraction for the peripheral traps then equals:

$$\frac{1{,}506.24 \text{ m}^2}{4 \times 8 \times 40 \text{ m}}$$

which in turn equals only 1.18 m. The total attractive distance then becomes half the distance between traps (i.e., 20 m + 1.18 m = 21.18 m).

This experiment was repeated in 1989 in the low-density population at Kirkwood. Again, a 7 x 7 grid of Multi-pher traps was deployed, but the distance between traps was only 20 m. In this experiment, each trap was baited with Biolure–89, which was considerably more potent than PVC–88 (see Table 26). The trap locations were randomized four times at 4- to 6-day intervals. At the 25 inner locations, catches averaged 3.67 ± 2.39 moths/trap, at the outer 24, 5.96 ± 2.51 (P = 0.002, df = 46). Using the same logic as above, the 3.67 moths captured from a 20- x 20-m area represent 0.0092 moths/m^2. The difference (2.29 moths/trap) represents an additional trapping area of 249.90 m^2/trap, or 5,996.07 m^2 for all 24 peripheral traps. This translates into an extra distance of:

$$\frac{5,996.1 \text{ m}^2}{4 \text{ x } 8 \text{ x } 20 \text{ m}}$$

which equals 9.37 m. The trapping distance then equals 10 m + 9.37 m = 19.37 m, which, in spite of the more potent lures, is in the same range as the 22 m calculated for the 1988 grid.

If we accept that the effective range of a trap is approximately 20 m, then traps 40 m apart should show little interference. Houseweart et al. (1981) found that the differences in catches between a central trap and the average of six traps spaced at uniform distances of 40 m between each other and 40 m from the central trap, were significantly less in only one of 16 instances. This supports the conclusion that the attractant distance is close to half the 40-m distance (i.e., 20 m). It is also important to realize that 40 m between traps is close to the practical limit for deployment of the traps in the field; any further and it is difficult to relocate the traps. Therefore, because interference was minimal at this distance, 40 m was chosen as the standard distance between traps.

Number of traps

The data from the two grids (in the previous section) also gave an indication of variability among traps and among trapping locations (Fig. 1). The distribution of catches by location shows less variability (CV = 30.9) than does the distribution by trap (CV = 40.2). Differences in catch among traps at these high densities are therefore more likely to be due to variability in the trap/lure combination than to location.

Miller and McDougall (1973) calculated the numbers of female-baited traps required to monitor low-density populations of the spruce budworm in New Brunswick. When the mean seasonal catch per trap averaged 2.0, 80 traps were required to give a standard error equal to 15% of the mean (which, for n=80, corresponds to a coefficient of variation of 134%). However, application of these results to the use of bucket traps and synthetic lures is questionable; virgin female moths are highly variable in attractiveness, and moths do not always stick to the sticky boards on first contact.

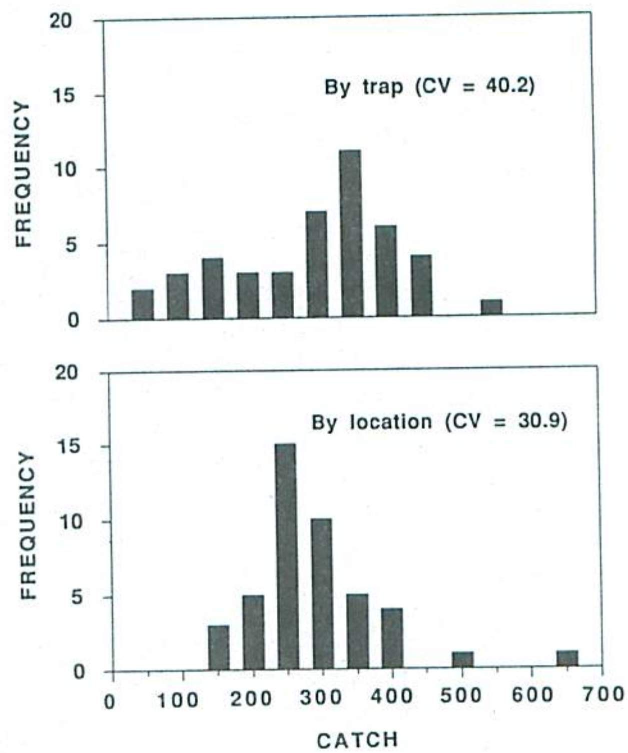


Figure 1. Frequency distributions for catches in Multi-pher traps deployed in a 7 x 7 grid with 40 m between traps at Black Sturgeon Lake in 1988. Positions of traps were re-randomized five times. Lower graph = distribution, by trap position; upper = distribution, by trap.

The number of Multi-pher traps required to give defined levels of precision can also be calculated from the 7 x 7 grid arrays described in the previous section. In the high-density populations (Black Sturgeon Lake), the average catch was 292.2 ± 115.8 ($\bar{x}$ ± SD) and in the low-density population (Kirkwood), 4.81 ± 3.28. From these data, the following numbers of traps are required to give the specified standard errors:

Standard error (as % of mean)	Population density High	Low
15	7.25	20.6
20	3.93	11.6
25	2.50	7.4
30	1.75	5.2
35	–	3.8
40	–	2.9

The decision on the numbers of traps to be deployed at each sampling point was made largely on practical grounds rather than being based on the number of traps required to give a specified level of precision. The first trials with synthetic lures were carried out with five traps per trapping location. This was an empirical decision, based on the belief that this provided a reasonable number to allow for variability among traps and locations. Trials in 1983 using double-funnel traps (Sanders 1984b) and in 1984 using Uni-traps established that there is a very high correlation between the mean trap catch from a three-trap cluster and that from a five-trap cluster (Fig. 2), which implies that three traps are as useful as five as an index of population density. Coefficients of variation for these data are shown in Figure 3. At low population densities, the CVs tend to be larger and more variable for three-trap clusters than for five-trap clusters, but there was little difference over much of the range of densities and it is questionable if the advantages of using five traps warrant the extra expense. Therefore, the three-trap cluster was recommended for operational use.

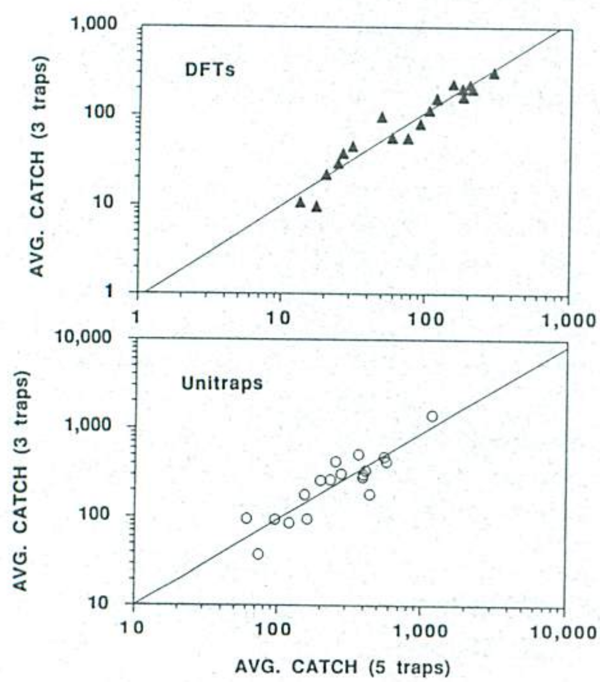


Figure 2. The relationship between the average catch per trap in clusters of three and five traps in northern Ontario in 1983. Top = double-funnel traps; bottom = Uni-traps. From Sanders (1984b).

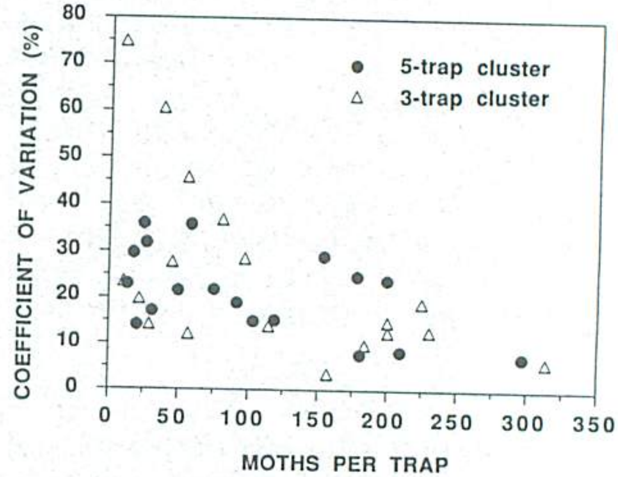


Figure 3. The relationship between coefficient of variation (CV) and mean number of moths caught per trap for clusters of three and five traps deployed over a range of population densities in Ontario.

Additional trials were run to determine if a further reduction in trap numbers per cluster could be justified. Comparisons were made between the catch in a single trap and the average from a two-trap cluster and that of a three-trap cluster (Table 4). If the catch from a three-trap cluster is taken as the "correct" estimate, then the two-trap cluster differed from the three-trap cluster in the categories designated in Table 4 only twice out of 16 comparisons. The single trap differed from the three-trap cluster five times, but in only one instance was the difference by more than one of the categories designated in Table 4 (306 for the single trap vs. 87.0 for the cluster). Therefore, one trap per location could be used with little loss in precision. However, traps are occasionally lost or destroyed, and lures can fall out during deployment. Therefore, the decision was made to use a three-trap cluster to safeguard against losing all the data for that location, which is more likely to happen if only one or two traps were used.

Conclusion

Based on the above results, it was recommended that three Multi-pher traps should be deployed at each trapping location, and that traps should be placed at head height (1.5 to 2.0 m), with 40 m between traps.

Trap Handling

There have been no reported problems in the deployment and subsequent handling of the Multi-pher traps, although users have complained of the need to wash the traps and of the space required to store them over-winter.

Table 4. Catches of male spruce budworm moths in clusters of one, two or three Uni-traps baited with PVC–87 or PVC–88 lures. Traps were deployed in mid-June before moth flight, and collected in early August after flight, at 16 locations in northwestern Ontario in 1987 and 1988.

Number of moths	Number (±SD) of traps 1	2	3
<10	4.3 ± 3.1	6.5 ± 2.1	4
	6.3 ± 2.9	1.0 ± 0	9
	8.0 ± 3.6	3.5 ± 3.5	8
	8.3 ± 7.8	5.5 ± 2.1	8
<30	11.3 ± 2.9	14.0 ± 4.2	13
	11.3 ± 3.5	12.5 ± 7.8	9
	25.0 ± 2.6	23.0 ± 8.5	39
<100	45.0 ± 9.2	28.5 ± 7.8	22
	77.7 ± 19.4	75.0 ± 8.5	81
	87.0 ± 66.1	77.0 ± 12.7	306
<300	102.7 ± 12.1	96.5 ± 0.7	103
	110.3 ± 34.0	131.5 ± 20.5	144
	133.7 ± 17.5	124.0 ± 11.3	79
	153.0 ± 12.2	203.5 ± 9.2	108
	204.7 ± 27.5	259.5 ± 7.8	235
	273.0 ± 46.5	192.5 ± 48.8	237
<1,000	585.0 ± 63.2	485.5 ± 10.6	541

Effect of insect repellents

A frequently expressed concern is the potential for contaminating the traps with insect repellent from the hands of the person deploying the traps. To determine if this is a problem, the following experiment was carried out in 1991 at Black Sturgeon Lake. Eighteen Multi-pher traps were baited with Biolure–90. Half of the traps were then liberally sprayed on the outside surfaces with Johnson "Deep Woods"®) insect repellent and all 18 traps were then deployed in a 9 x 2 rectangle at a spacing of 20 m. The traps were deployed on 24 June, moved up one position in the grid each day and removed on 28 June. Catches in the untreated traps averaged 33.6 ± 10.5 moths over the 4-day trapping period; in the traps treated with the repellent, catches averaged 33.4 ± 9.8 moths, clearly a nonsignificant difference. Furthermore, daily catches were also not significantly different. It was therefore concluded that this insect repellent has no effect on the capture of moths in the pheromone-baited traps.

Effect of contamination with pheromone

Evidence has been obtained that the traps become contaminated with the pheromone. This raises the question of whether this contamination could significantly affect catches in subsequent years. If it does, then the next question is how the contamination can be avoided or dealt with.

In 1987, traps that had been left unwashed after exposure to pheromone in 1986 were deployed with and without pheromone in a low-density population (Kirkwood). The results (Table 5) gave no evidence of contamination. The experiment was repeated in 1988 in a high-density population (Black Sturgeon Lake), and this time there was evidence of serious contamination (Table 5); catches were not significantly different among traps, washed or unwashed, with or without a lure. However, these results could also be interpreted to mean that moths in high-density populations blunder into traps, regardless of the pheromone source, as has been reported in previous work (Sanders 1978). Therefore, a similar experiment to that of 1988 was carried out in 1989, with the inclusion of brand new traps that had never been exposed to pheromone. The results (Table 6) confirm that at least during a budworm outbreak, a considerable number of moths blunder into the traps (new, unbaited traps caught 13.5 moths per trap vs. 67.5 moths per new, baited trap). The results also show unequivocally that there was significant contamination of the traps (used, unwashed, unbaited traps caught 180 moths per trap vs. 13.5 moths per new, unbaited trap). Washing the traps reduced the level of contamination (catches decreased from 185.0 to 57.5 per trap), but did not remove it completely. As well, contaminated, baited traps caught

Table 5. Catches of male spruce budworm moths in Multi-pher traps baited with PVC–87 or unbaited, in a low-density population (Kirkwood 1987) and a high-density population (Black Sturgeon Lake 1988). One series of traps was washed in detergent after use the previous season, one series was unwashed. Numbers in the same column followed by the same letter are not significantly different at p = 0.05.

Trap	Number (±SD) of traps: Low-density population, Kirkwood 1987 (n = 5)	High-density population, Black Sturgeon Lake 1988 (n = 10)
Washed		
with lure	7.8 ± 3.5 a	380.5 ± 93.6 a
no lure	0 b	327.6 ± 104.3 a
Unwashed		
with lure	6.4 ± 2.3 a	344.2 ± 148.0 a
no lure	0 b	239.8 ± 119.2 a

significantly more moths than uncontaminated (new) baited traps. Levels of contamination were presumably affected by the strength of the lure in the trap, and how long it had been left in the trap. Unfortunately, no records were kept of these parameters, so no further interpretation of the results is warranted. In another experiment in 1989, unbaited, washed traps were deployed along with baited, washed traps at a number of locations around Sault Ste. Marie for which population densities were low. Contamination did not seriously affect catches at these low densities (Table 7).

Table 6. Catches of male spruce budworm moths in Multi-pher traps baited with PVC–89 or unbaited, in a high-density population (Black Sturgeon Lake), deployed at head height 8–18 July 1989. One series of traps was brand new, one series was baited with PVC–88 in 1988 and washed after use, and one series was baited with PVC–88 in 1988 and left unwashed. Numbers in a column followed by different letters are significantly different at p = 0.05 using Tukey's procedure for multiple comparisons.

	Numbers of moths	
Trap	With PVC lure (n = 10)	Unbaited (n = 10)
New, unused trap	67.5 b	13.5 c
Washed in 1988	151.7 a	57.5 b
Unwashed in 1988	179.4 a	185.0 a

Table 7. Catches of male spruce budworm moths in Multi-pher traps deployed in clusters of three, each baited with PVC–89 or Biolure–89, at seven locations near Sault Ste Marie from 23 June until early August 1989.

	Number of moths		
Location	PVC	Biolure	Unbaited
1	5.3	3.3	0.7
2	6.3	0.3	0.3
3	11.0	9.3	0
4	12.0	9.7	1.3
5	19.7	9.7	0
6	35.7	10.3	0
7	45.7	19.7	1.0

In 1990, further experiments were carried out to determine the nature of trap contamination. The objective of the first experiment was to determine which part of a Multi-pher trap became most heavily contaminated. The contaminated traps had all been used in 1989, when they were baited with PVC–87. One series of traps had been left unwashed, one set washed with detergent, one set washed with a 1% solution of chlorine bleach, and one set left out for 1 week in sunlight. Brand new, unused Multi-pher traps were used to provide the checks. Different parts of the used traps were incorporated into the new traps. Traps baited with Biolure–90 and unbaited traps were also deployed. The experiment was carried out at Black Sturgeon Lake, and, on a slightly reduced scale, at Kirkwood (Table 8). The results confirmed that the used traps were contaminated, and that washing or exposure to the sun did little to remove the contamination. Attempts to determine which parts of the trap were most contaminated, however, were unsuccessful. New traps with the various contaminated parts incorporated into them caught no more than the brand new traps with no contaminated parts. It was therefore concluded that all parts have some contamination, and it is the sum of this contamination that results in significant catches. The second experiment in 1990 was to determine if IPS Uni-traps were also contaminated by previous use. Traps that had been used in 1989 were compared with brand new traps. Both sets were baited with Biolure–90. Catches in the unbaited, used traps were not significantly different from those in the unbaited new traps (Table 9). This indicates that contamination of Uni-traps is far less than for the Multi-pher traps. The reason for this is unknown; both types of trap were exposed under identical conditions to the same lures for the same length of time. It is possible that there is a difference in the type of plastic used.

Logically, the degree of contamination will be related to the potency of the pheromone source that has been in the trap. An experiment was therefore carried out in 1991 to test this, and to obtain an indication of how much contamination could be expected from exposure to lures of known potency. During January 1991, rubber septa were loaded with 100-µL aliquots of hexane containing 1, 10 or 100 µg of *E*:*Z*–11–tetradecenal. After aging the septa for 2 days, they were placed in either brand new Multi-pher traps or brand new Uni-traps, with eight traps for each treatment. The traps were then placed in a fume hood and left for 4 weeks, after which they were stored in an unheated outdoor storage shed in cardboard boxes, with a separate box for each treatment. In June 1991, these traps were deployed at Black Sturgeon Lake in a grid pattern along with eight brand new, unbaited traps and eight brand new traps, each baited with Biolure–90. The traps were checked and moved up one position in the grid each day for 4 days. The accumulated catches (Table 10) give no indication of contamination. Possibly, these loadings were too low or the air flow in the fumehood did not allow the phero-

Table 8. Contamination experiment #1, 1990. Catches of male spruce budworm moths in Multi-pher traps baited with Biolure–90 and in unbaited Multi-pher traps that had contained spruce budworm lures (PVC–87) or jack pine budworm (JPBW) lures (PVC–89 from the New Brunswick Research Productivity Council) the previous year (1989), compared with catches in new, unused baited and unbaited traps. Traps were deployed at Kirkwood 27 June and 1 August and at Black Sturgeon Lake 12 July–14 August.

		Number (±SD) of moths	
Type of trap		Low density (Kirkwood)	High density (Black Sturgeon Lake)
New	baited	2.4 ± 1.8	86.0 ± 27.1
	unbaited	0.4 ± 0.7	2.4 ± 2.2
Used, washed	baited	2.8 ± 2.4	–
	unbaited	1.9 ± 1.2	30.1 ± 26.8
Used, unwashed	baited	2.8 ± 1.6	87.4 ± 19.0
	unbaited	1.4 ± 0.7	23.1 ± 16.8
Used, chlorine washed	unbaited	–	25.2 ± 16.8
sunlight + wash	unbaited	–	25.5 ± 12.8
New + used bucket	baited	–	115.1 ± 17.4
	unbaited	–	3.8 ± 3.2
New + used "shuttlecock"	baited	–	115.7 ± 36.1
	unbaited	–	4.9 ± 5.0
New + used lid	baited	–	108.1 ± 24.8
	unbaited	–	2.9 ± 3.4
Used for JPBW, unwashed	baited	5.1 ± 3.0	144.4 ± 28.7
washed	baited	3.1 ± 3.7	126.9 ± 26.1
chlorine	baited	–	114.6 ± 28.8

Table 9. Contamination experiment #2, 1990. Numbers of male spruce budworm moths captured in Uni-traps (either all-green or tri-colored) baited with Biolure–90 or unbaited. Traps were either brand new or used the previous year with PVC–87 lures. Traps were deployed at Black Sturgeon Lake 12 July–14 August.

Trap color	Condition	Lure	Number of moths caught
Green	new	baited	92.1 ± 14.4
	new	unbaited	0.8 ± 0.7
Tri-color	new	baited	194.3 ± 33.7
	new	unbaited	1.9 ± 1.5
	used	baited	221.4 ± 53.0
	used	unbaited	3.6 ± 3.4
	used + chlorine washed	unbaited	1.4 ± 1.1
	used + detergent washed	unbaited	2.0 ± 2.6

mone to remain in contact with the traps for long enough for it to be adsorbed.

The results of all these experiments indicate that traps can become contaminated by pheromone from the lures. However, the effects are variable and probably depend upon the potency of the pheromone source and the length of time the lures remain in the traps. IPS Uni-traps are less prone to contamination than Multi-pher traps. Even when traps are heavily contaminated, as in 1989, the effects on subsequent catches are more pronounced in high-density populations. This is consistent with observations on budworm moth behavior. At high densities, males are conspicuous, "hovering" around the branches (Greenbank et al. 1980, Sower and Daterman 1985), which suggests that when densities are high the pheromone is effective in attracting males to a specific source only at short range. No such hovering behavior has been seen during many hours of observation in low-density populations (C.J. Sanders and G.S. Lucuik, Forestry Canada, Sault Ste. Marie, Ont., unpublished data), but males have been seen homing in on pheromone sources from distances of more than 10 m. Moreover, data from traps laid out in 7 x 7 grids (see above) in a high-density population show that catches in the peripheral 24 traps were not significantly higher than in the central 25; however, the outer traps did catch significantly more than the inner traps at low densities. This may indicate that pheromone orientation occurs over longer distances in low-density populations because of

Table 10. Contamination experiment #3, 1991. Catches in Multi-pher and Uni-traps that had contained rubber septa loaded with spruce budworm pheromone for 4 weeks, compared with catches in new traps, either baited with Biolure-90 or unbaited. Traps were deployed at Black Sturgeon Lake 24–28 June.

Treatment of trap	Bait	Number of moths	
		Multi-pher	Uni-trap
Contaminated			
septa with 1 µg	no	3.6 ± 2.4	1.2 ± 1.0
septa with 10 µg	no	3.0 ± 2.3	0.8 ± 0.7
septa with 100 µg	no	3.1 ± 2.0	2.0 ± 2.0
New (uncontaminated)			
	yes	34.8 ± 6.7	41.6 ± 8.5
	no	4.5 ± 2.3	0.9 ± 1.4

less competition between the lures and the female moths. This must be verified, but if true it means that catches in low-density populations are dependent upon male moths following plumes over a considerable distance, whereas at high densities, most may be attracted over only a short range.

Contamination did not increase catches in baited traps in low-density populations, and if trapping is designed to monitor population fluctuations at low densities, then there is perhaps no cause for concern about contamination. However, another potential problem is that contamination with one pheromone could seriously affect the number of insects of another species caught if the trap is used for monitoring that species, particularly if the pheromones are antagonistic, as in the case of the spruce budworm and the jack pine budworm (*Choristoneura p. pinus* Free.) (Sanders et al. 1977). Contamination will therefore always raise questions, and should be avoided. Two solutions are possible: either a method of washing the traps must be devised to remove the contamination, or a suitable disposable trap must be developed that can be used only once and then discarded. Existing designs have been evaluated (Sanders 1988), but none were found to be suitable. Both these possibilities are under further investigation.

Conclusion

Contamination of traps by insect repellent during handling is not a problem. Contamination with pheromone from previous use is also not a problem in low-density populations, provided that the lures are not of high potency and that the traps are used for the same species from year to year. However, to avoid both the potential problems and the need for storage of traps, a disposable, low-cost trap is desirable.

Insecticide

The volatile insecticide dichlorvos (DDVP) is commonly used to kill moths in non-sticky, high-capacity traps. In early experiments with high-capacity traps for the spruce budworm, it was recommended that the insecticide should be suspended inside the bucket of the trap to keep it above the accumulation of dead moths. This practice is still recommended in trapping programs for some species. However, it is time consuming and requires that the insecticide formulation be handled, and there has been no evidence that moths remain alive longer when the insectide formulation is just dropped into the bucket. Presumably, insecticide that is adsorbed by the dead moths is re-released into the air-space even when the insecticide strip is covered by dead moths, and this maintains a fairly constant concentration inside the bucket. It is therefore now recommended that the insecticide formulation be simply dropped to the floor of the bucket.

Initial tests in the case of the spruce budworm were carried out with commercial formulations of DDVP in resin (Vapona®, Strike®, Fly-tox® or No-pest® strips). All such formulations were similar in size and shape and incorporated the same concentration of dichlorvos, 18.6% by weight. One-quarter of a strip was placed in each trap. The disadvantage of these formulations is that the individual strips are too large, and must be cut up, which requires extra handling by the user and consequently more exposure to the insecticide. The manufacturer of the Uni-trap (IPS) included small pellets containing DDVP with the traps, each approximately 2.5 x 2.5 cm x 0.5 cm thick. These came in packets of 10 and did not need to be cut up, which was an advantage over the Vapona-type strips. However, when the decision was made to use the Multi-pher traps, these pellets were not available. Therefore, for the first year of the cooperative trials (1985), it was decided to use an alternative formulation — flea collars for cats, which were being used in the U.S. at that time in gypsy moth (*Lymantria dispar* L.) traps (C. Schwalbe, USDA, Agricultural Research Service, personal communication). Unfortunately, the type of flea collar obtained contained not dichlorvos as intended, but tetrachlorvinphos (TCVP), which is a non-volatile insecticide. As a result, traps in 1985 captured fewer moths than anticipated, and many of the captured moths remained alive, which created problems in counting. Meanwhile, Health–

Chem Corp. developed a DDVP formulation (Vaportape II) in the U.S. that contained 9.95% DDVP (w/w), specifically for use in their "Lure'n'Kill" milk-carton traps for monitoring gypsy moths. Vaportape II strips are packaged individually, and so require even less handling than the IPS pellets. These were chosen for the budworm trials in 1986 and have been used in all jurisdictions except Québec, where Vapona-type formulations are still used. Vaportape II has been registered for use in pheromone traps in the U.S., and has recently (1989) been registered for use in Canada by the Pesticides Directorate of Agriculture Canada (registration # 21222).

Experiments have been carried out to evaluate Vaportape II by comparing its effectiveness with the other formulations. In the first experiment, carried out in a fume hood, a sample of the test formulation was placed in a 500-mL flask, which was covered with a glass plate. After 1 hour, male spruce budworm moths were placed in the beaker, five at a time. Their subsequent fate was observed, and times were recorded for each male until it (a) became incapable of coordinated movement, and (b) became motionless. The formulations tested were (i) Vaportape II, (ii) one-quarter of a Vapona strip, (iii) an IPS pellet, and (iv) one-half of a flea collar containing TCVP. The flea collars were almost ineffective; no males were incapacitated during the first hour, and some were still alive after a 24-hour exposure, which confirms the concerns over the 1985 results when flea collars were used. The results with the other formulations (Fig. 4) indicate that the one-quarter Vapona strip was the most potent, followed by the Vaportape II and then the IPS pellet. The results also show that the effectiveness of the insecticide formulations decreases over time, although both the Vapona and the Vaportape II were still very effective after 6 weeks. The IPS pellets showed a loss in potency after 4 weeks, which may be attributable to their small size.

In a second experiment, the effect of the insecticide formulations on the responses of male spruce budworm in a wind tunnel was recorded. Earlier experiments (Sanders 1986b) had shown that the presence of a Vapona strip in a trap lined with Stickem® resulted in a lower catch. This led to the conclusion that dichlorvos has a repellent effect. Samples of each insecticide formulation that had been aged in a fume hood for 1 week were placed individually in Multi-pher traps, each of which also contained a PVC pellet (0.03% pheromone w/w). The traps were hung in a wind tunnel and male spruce budworm moths were released about 1 m downwind in the plume from the trap. The numbers of males

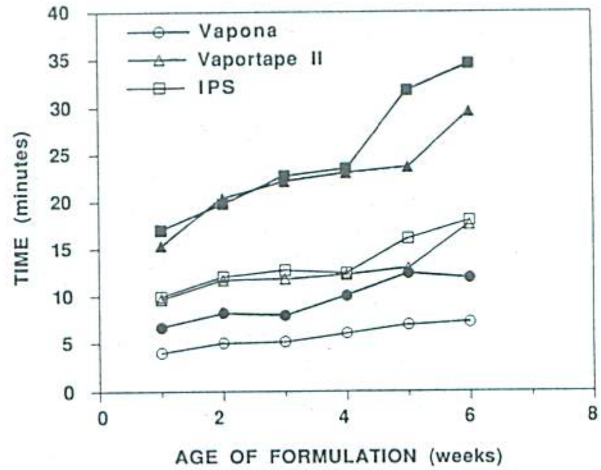


Figure 4. Times taken for different formulations of dichlorvos (DDVP), aged from 1 to 6 weeks, to incapacitate and kill male spruce budworm moths in covered 500-mL beakers. Open symbols indicate times to incapacitation; solid symbols, times to death of moths.

that responded by wing-fanning, flying to the trap, reaching the trap opening, and entering the trap were recorded. The presence of a Vapona strip or the IPS pellet reduced catches significantly (Table 11); the flea collar and the Vaportape II had no significant effects.

In 1989, the effectiveness of the different insectide formulations was evaluated in the field. Multi-pher traps containing the different formulations were baited with PVC–89 (0.03% w/w) and deployed in either a low-density population (Kirkwood) or a high-density population (Black Sturgeon Lake). Each formulation was replicated 10 times, and 10 traps contained no insecticide. For the Vaportape II, three treatments were included: unused strips obtained in 1989, unused strips from 1988, and 1988 strips that had been used in 1988 (although the duration of exposure was not recorded). Results are shown in Table 12. In the high-density population, there were no significant differences in average catch. However, the two lowest average catches were in traps that contained no insecticide or that contained the flea collars. In addition, there were many live moths in these traps, which generated clouds of moth-scales when the traps were opened, and the moths were in very poor condition, which made it difficult to count them, as was also recorded by Grimble (1987). In the low-density population, catches in the traps that contained no insecticide or flea collars were again lower than in traps that contained Vapona or the 1988 Vaportape II; however, differences between Vapona and any of the different Vaportape II preparations were not significant.

In 1990, a further comparison was made between Vaportape II and Vapona strips as part of an experiment that compared the potency of batches of Biolures. Multi-pher traps were baited with previously unused Biolures manufactured in 1988, 1989 and 1990. One set of traps with the 1990 lures contained Vaportape II insecticide strips; the other set contained one-quarter of a Vapona strip. Each treatment was replicated five times. The traps were deployed at Black Sturgeon Lake on 11 July and left until the end of the flight season. The results (Table 13) showed no difference in catch between the traps baited with Biolure–90 that contained either the Vaportape II or the Vapona strips.

Conclusion

Based on the above results, it is recommended that Vaportape II strips be used in non-sticky pheromone traps for monitoring spruce budworm populations. Ideally, these should be suspended inside the trap bucket, but there is no loss in efficacy if they are dropped to the floor of the bucket. The Vaportape II shows less repellency than the other dichlorvos formulations, is almost as effective as the most potent (Vapona-type) in terms of both speed of knock-down and in trap catch, and is now registered for use in both Canada and the United States. Furthermore, some of the Vapona-type formulations have been withdrawn from the market and are no longer available.

Lures

The ideal lure should protect the pheromone from degradation and provide a constant, predetermined release rate that lasts for the entire flight season. When the protocols for the program were being drawn up, it was decided to aim for a release rate close to that of a virgin female moth. This was based on the reasoning that males have evolved to respond optimally to the female release rate and that any deviations from

Table 11. Number of male spruce budworm moths in a wind tunnel that responded to Multi-pher traps containing three different formulations containing dichlorvos (DDVP), and one (flea collars) containing TCVP. All traps were baited with 0.03% PVC lures. Numbers in the same column followed by different letters are significantly different at p = 0.05 (G^2 test). The absence of letters indicates no significant differences.

		Number of moths			
Insecticide	n	Wing fanning	Touching trap	At trap opening	Entering trap
Check[a]	50	26 a	31	31	29 a
Vapona	45	12 ab	22	22	16 b
Vaportape II	45	13 ab	29	29	27 ab
IPS pellet	45	8 b	19	19	16 b
Flea collar	45	15 ab	29	27	26 ab

[a] no insecticide

Table 12. Catches of male spruce budworm moths in Multi-pher traps baited with PVC–89 and containing different formulations of insecticide. The Vaportape II was of three types: new in 1989, obtained but unused in 1988, and obtained and used in 1988. Numbers in the same column followed by different letters are significantly different at p = 0.05 (G^2 test). The absence of letters indicates no significant differences.

		Number (± SD) of moths	
Insecticide		High-density population (Black Sturgeon Lake)	Low-density population (Kirkwood)
Vaportape II	1989	129.3 ± 58.0	8.9 ± 5.3 ab
	1988	149.8 ± 73.8	10.6 ± 6.3 a
	1988 used	127.1 ± 81.7	8.5 ± 6.4 ab
IPS pellet		144.8 ± 45.4	6.9 ± 3.5 ab
Flea collar		100.2 ± 29.4	3.9 ± 3.1 b
Vapona strip		121.8 ± 49.5	11.7 ± 4.1 a
Check (no insecticide)		93.0 ± 37.2	3.3 ± 2.7 b

Table 13. Catches of male spruce budworm moths in Multi-pher traps baited with batches of Biolure from different years, and containing either a Vaportape II insecticide strip or one-quarter of a Vapona strip. Traps were deployed at Kirkwood 27 June–1 August 1990 (n = 5) and at Black Sturgeon Lake 11 July–14 August 1990 (n = 5).

		Number of moths (± SD)	
Biolure	Insecticide	Low density (Kirkwood)	High density (Black Sturgeon Lake)
1988	Vaportape II	61.8 ± 4.1	604.0 ± 63.3
1989	Vaportape II	3.6 ± 1.2	183.5 ± 52.8
1990	Vaportape II	5.6 ± 1.6	180.8 ± 35.1
1990	Vapona	8.8 ± 4.9	185.6 ± 19.1
Unbaited	Vaportape II	2.8 ± 1.6	40.0 ± 25.0

this rate might result in aberrant behavior. During the early development of the trapping program (in 1973), a PVC formulation was chosen as the dispenser for the pheromone. At that time, commercial formulations were unavailable and the PVC lures could be formulated easily in a basic laboratory. Laboratory tests showed that a loading of 0.03% of 95:5 *E*:*Z*–11–tetradecenal (w/w) in a PVC pellet 4 mm in diameter and 10 mm long gave a release rate of about 20 ng/hour, close to that of a calling female moth, and field tests showed that these lures attracted about the same number of males as did female moths (Sanders 1981b). This lure was therefore chosen for the operational program.

Release rates from PVC lures formulated from 1980 through 1988 were analyzed using one of two methods: gas chromatography, by RPC, or a bioluminescent technique (Meighen et al. 1983), by E.A. Meighen (Univ. McGill, Montreal, Que.). The results of the first 6 years of analysis (1980 through 1985) have been published (Sanders and Meighen 1987). Additional previously unpublished data for lures manufactured from 1984 through 1988 are tabulated in Table 14 and are shown graphically in Figure 5. Release rates were highest from the PVC–85 lures and lowest from the PVC–84 lures, with a six- to 10-fold difference between the two. A 10-fold difference in release rate affects male response, and hence capture rates, significantly (Sanders 1990b). The PVC–85 lures would therefore be expected to give significantly higher catches than the PVC–84 lures. However, the opposite occurred (Table 15); in fact, lures that had been refrigerated at –11°C showed increased

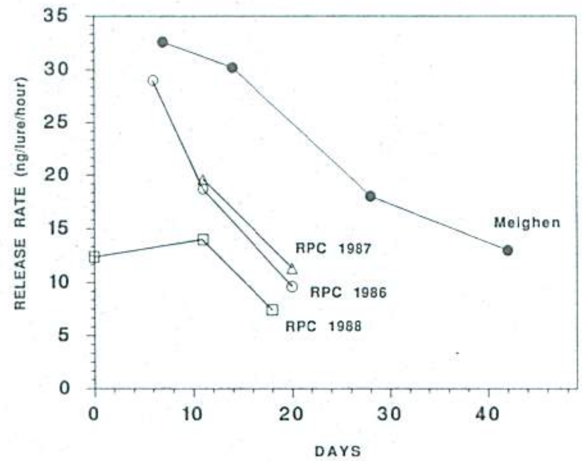


Figure 5. Estimated release rates of E–11–*tetradecenal (0.03% w/w) from PVC lures, determined using the bioluminescent technique of Meighen et al. (1983) (Biochemistry Dept., McGill Univ., Montreal, Que.), and using gas chromatography by the New Brunswick Research and Productivity Council (RPC; see Table 14 for error estimates).*

Table 14. Release rates of pheromone from PVC pellets (4-mm diameter, 10 mm long, loaded with 0.03% pheromone w/w) used in the operational monitoring program, 1984–1988. Numbers in parentheses indicate the number of lures in the sample.

		Release rate of pheromone (ng/hour), by number of days of exposure							
Analyst	Lot	0	6–7	10–11	14	18–21	28	35	42
Meighen[a]	84	–	11.5	–	5.4	5.0	3.7	2.6	2.6
	85	–	66	–	53	–	–	–	–
	86A	–	32.6 ± 2.1	–	30.2 ± 2.7	–	18.2 ± 1.1	–	13.0 ± 1.6
	86B	–	26.4 ± 1.4	–	25.2 ± 1.0	–	–	–	–
	86C	–	27.8 ± 1.4	–	25.7 ± 1.6	–	–	–	–
RPC[b]	86	–	29.0 ± 4.7	18.7 ± 4.5	–	9.6 ± 3.3	–	–	–
			(4)	(19)		(20)			
	87A	–	–	19.2 ± 7.7	–	12.3 ± 4.7	–	–	–
				(10)		(9)			
	87B	–	–	19.9 ± 10.2	–	10.4 ± 3.8	–	–	–
				(10)		(10)			
	88	12.4 ± 0.7	–	14.0 ± 0.7	–	7.4 ± 0.9	–	–	–
		(20)		(20)	(20)				

[a] Determined by the bioluminescence technique of Meighen et al. (1983).

[b] Determined by gas chromatography at the New Brunswick Research Productivity Council (RPC).

Table 15. Catches of male spruce budworm moths in traps baited with PVC lures (0.03% pheromone w/w) manufactured in different years and stored at –11°C. Pherocon 1CP traps were used in 1983 and 1984, IPS Uni-traps in 1985. Traps were deployed at Black Sturgeon Lake for the periods shown in the table. Numbers in the same column followed by different letters are significantly different at p = 0.05 (Tukey's procedure for multiple comparisons).

Year of PVC manufacture	Number of moths, by year and test date: 1983 12–13 July	1984 11–13 July	1985 14 July–7 August	Catch in 1983 as % of 1980 catch
1980	123.8 ± 6.8 a	–	–	100
1981	80.3 ± 5.7 b	–	–	65
1982	68.9 ± 10.7 bc	–	–	56
1983	46.9 ± 5.4 c	141.8 ± 15.8 a	–	38
1984	–	88.6 ± 13.2 b	126.1 ± 9.5 a	24
1985	–	–	76.6 ± 10.0 b	15

potency after several years of storage (Sanders and Meighen 1987; Table 15). Moreover, tests of the comparative potency of PVC lures that had been "aged" for different lengths of time showed that potency declines significantly over a 4- to 6-week period (Sanders and Meighen 1987), which is the length of time that lures are deployed in the field. These anomalies are sufficient cause for questioning the use of the PVC formulation, at least for aldehydes.

Types of lure

Evaluation was therefore carried out on four alternative commercial lures: Hercon Laboratories Corp. (Emigsville, PA) plastic laminate flakes, Conrel (currently Scentry Inc., Buckeye, AZ) fibers, Consep Membrane Inc. Biolures, and vials produced by IPS. In addition, rubber septa, which are commonly used in monitoring and research programs with other species, were also evaluated. Manufacturers were requested to provide a release rate of 20 to 40 ng/hour, close to the release rate of a calling female spruce budworm moth. Pheromone for each formulation was obtained by the individual manufacturers (sources now unknown) and loadings were at the discretion of the manufacturers. Lures of each type were aged artificially in a fume hood for various lengths of time, and then placed in traps in the field simultaneously to determine the effects of aging on catch. Results up to 1986 have been published previously (Sanders and Meighen 1987). Subsequent results from 1986 through 1991 are presented in their entirety in Tables 16 through 25 and in Figures 6–10.

The results from these experiments can be summarized as follows: Fibers proved inconsistent (Sanders and Meighen 1987), and it is questionable if the fibers used were appropriate for use with aldehydes (Weatherston et al. 1985), although new formulations that have not been tested for the spruce budworm are now available (Golub et al. 1983). As with the PVC lures, septa showed a decline in potency over time, which is an undesirable trait (Fig. 8 and 9). Flakes showed only a minimal decline in potency, but catches were inexplicably low (Sanders and Meighen 1987), and as with the PVC and the fibers, release rates can be expected to follow a first-order decay curve (i.e., the rate of release is proportional to the amount of material remaining in the lure). Both the IPS vials and the Biolures operate on the principle that an air space in contact with the pheromone inside the lure will remain saturated with pheromone as long as there is some pheromone left, and that the release rate from the lure is therefore independent of the amount remaining and should give a constant release rate right up to the time the pheromone is completely evaporated. The vials did indeed have a constant capture rate (Sanders and Meighen 1987), but the lures were too potent and they are bulky and cumbersome. The Biolures also gave a constant rate of capture, and would have been accepted for operational use early in the program but for the fact that the release rates, and consequently the capture rates, were also on the high side (Grimble 1987, Sanders and Meighen 1987; Fig. 6–10).

Table 16. Catches of male spruce budworm moths in 1986 in IPS Uni-traps baited with different types of lure aged for different lengths of time. Tests were conducted at Black Sturgeon Lake in 1986: BSL 1 = traps deployed 3–10 July; BSL 2 = traps deployed 10–17 July. Numbers in the same column followed by different letters are significantly different at p = 0.05 (Tukey's procedure for multiple comparisons).

Lure		Number (± SD) of moths caught, by number of weeks after placement in the field							
		1	2	3	4	5	6	7	8
PVC–85	BSL 1	22.4 ± 5.7 ab	30.4 ± 7.2 a	24.0 ± 14.4 ab	33.0 ± 25.8 a	25.2 ± 16.4 ab	7.0 ± 6.8 b	7.6 ± 5.9 b	–
	BSL 2	41.2 ± 10.0 cde	84.4 ± 37.1 b	125.2 ± 50.3 a	84.4 ± 36.0 b	73.0 ± 21.9 bc	61.6 ± 11.3 bcd	22.2 ± 11.7 e	29.4 ± 13.2 de
PVC–86	BSL 1	51.6 ± 33.4 a	65.2 ± 29.4 a	62.2 ± 36.2 a	63.8 ± 35.4	52.0 ± 41.1 a	36.8 ± 19.8 a	36.2 ± 12.6 a	–
	BSL 2	75.4 ± 42.0 a	184.4 ± 170.6 a	220.8 ± 164.8 a	208.6 ± 142.5 a	232.0 ± 128.2 a	228.4 ± 73.1 a	224.0 ± 62.7 a	154.0 ± 76.8 a
Biolure–A	BSL 1	41.0 ± 13.9 a	34.8 ± 10.6 a	25.2 ± 8.3 a	27.6 ± 8.2 a	24.0 ± 18.8 a	–	–	–
	BSL 2	66.0 ± 28.6 a	87.0 ± 46.0 a	82.4 ± 28.3 a	61.4 ± 14.2 a	77.6 ± 23.1 a	101.8 ± 55.3 a	–	–
Biolure–B	BSL 1	45.8 ± 6.3 a	41.4 ± 19.9 a	35.4 ± 21.8 a	36.0 ± 14.2 a	40.4 ± 11.4	–	–	–
	BSL 2	50.8 ± 20.9 b	103.0 ± 33.6 a	115.4 ± 32.4 a	80.6 ± 30.9 ab	103.8 ± 21.1 a	100.8 ± 37.5	–	–
Biolure–C	BSL 1	52.4 ± 7.5 a	32.4 ± 10.3 b	17.8 ± 5.0 b	27.8 ± 16.5 b	26.8 ± 10.9 b	–	–	–
	BSL 2	54.8 ± 19.7 a	83.6 ± 26.4 a	77.6 ± 21.6 a	74.6 ± 32.8 a	76.2 ± 22.2 a	89.4 ± 25.5 a	–	–
IPS–Bl	BSL 1	37.2 ± 18.3 a	43.4 ± 22.1 a	38.8 ± 10.2 a	–	–	–	–	–
	BSL 2	45.8 ± 14.9 a	93.4 ± 61.0 a	96.6 ± 50.2 a	94.2 ± 30.1 a	–	–	–	–
IPS–0	BSL 1	21.2 ± 13.0 a	33.0 ± 18.3 a	–	–	–	–	–	–
	BSL 2	61.0 ± 25.6 a	52.8 ± 22.4 a	50.8 ± 19.7 a	–	–	–	–	–

Table 17. Catches of male spruce budworm moths in 1986 in Pherocon 1C traps baited with different types of lure aged for different lengths of time at Kirkwood: KWD 1 = traps deployed 3–10 July; KWD 2 = traps deployed 10–17 July. Numbers in the same column followed by different letters are significantly different at p = 0.05 (Tukey's procedure for multiple comparisons).

Lure		Number (± SD) of moths caught, by number of weeks after placement in the field							
		1	2	3	4	5	6	7	8
PVC–85	KWD 1	13.2 ± 5.7 bc	26.8 ± 6.3 a	19.2 ± 9.7 b	13.4 ± 3.5 bc	11.0 ± 4.1 c	2.6 ± 2.5 d	3.4 ± 1.3 d	–
	KWD 2	2.2 ± 1.1 b	5.2 ± 2.9 ab	6.2 ± 3.6 ab	8.4 ± 5.4 a	9.2 ± 3.6 a	6.2 ± 3.7 abd	2.4 ± 1.3 b	–
PVC–86	KWD 1	27.2 ± 6.4 a	21.8 ± 7.1 a	15.4 ± 5.9 b	12.0 ± 3.5 bc	9.2 ± 2.3 bc	9.4 ± 3.8 bc	5.8 ± 2.5 c	–
	KWD 2	9.2 ± 4.1 a	2.8 ± 1.9 b	4.6 ± 2.9 ab	7.4 ± 6.1 ab	7.2 ± 4.1 ab	4.6 ± 2.7 ab	4.8 ± 3.0 ab	–
Biolure–A	KWD 1	26.2 ± 12.8 a	26.2 ± 19.9 a	23.4 ± 15.6 a	20.8 ± 8.1 a	21.8 ± 10.8 a	–	–	–
	KWD 2	6.4 ± 3.1 a	12.2 ± 11.5 a	19.4 ± 15.7 a	16.4 ± 14.2 a	8.4 ± 7.0 a	13.6 ± 12.8 a	–	–
Biolure–B	KWD 1	18.8 ± 10.9 a	19.0 ± 14.2 a	34.0 ± 14.2 a	22.0 ± 16.9 a	15.6 ± 18.2 a	–	–	–
	KWD 2	2.0 ± 1.2 b	8.4 ± 3.6 ab	12.0 ± 8.7 a	10.0 ± 6.2 ab	9.6 ± 5.9 ab	10.0 ± 9.8 ab	–	–
Biolure–C	KWD 1	25.2 ± 10.1 a	16.8 ± 14.1 a	32.0 ± 11.9 a	16.4 ± 9.1 a	18.4 ± 17.0 a	–	–	–
	KWD 2	7.8 ± 3.0 b	27.4 ± 20.5 a	16.2 ± 14.5 ab	8.8 ± 7.2 b	7.6 ± 4.8 b	4.0 ± 3.7 b	–	–
IPS–BI	KWD 1	32.0 ± 11.0 a	30.4 ± 20.5 a	32.0 ± 13.7 a	–	–	–	–	–
	KWD 2	–	14.4 ± 12.1 a	10.0 ± 3.9 a	11.0 ± 3.7 a	–	–	–	–
IPS–0	KWD 1	26.6 ± 14.1 a	–	22.8 ± 11.5 a	–	–	–	–	–
	KWD 2	23.4 ± 5.5 a	8.4 ± 5.7 b	13.8 ± 8.9 b	–	–	–	–	–

Table 18. Catches of male spruce budworm moths in Multi-pher traps baited with PVC–87, pre-aged in a fume hood. Tests were conducted at Kirkwood in 1987.

	Number (±SD) of moths caught, by number of weeks of pre-aging					
Test period	1	2	3	4	5	6
23–30 June	0.8 ± 0.9	0.9 ± 0.9	1.6 ± 1.4	1.2 ± 1.3	1.7 ± 1.6	0.8 ± 0.9
23 June–7 July	1.1 ± 1.0	1.4 ± 1.6	0.7 ± 0.7	0.8 ± 0.6	0.7 ± 0.9	0.3 ± 0.5

Table 19. Catches of male spruce budworm moths in 1987 in Multi-pher traps baited with three types of Biolure that were pre-aged in a fume hood, with rubber septa, or with PVC lures. Traps were deployed at Black Sturgeon Lake 13–28 July (n = 5).

	Number (±SD) of moths caught, by number of weeks of pre-aging				
Lure	1	2	3	4	5
Biolure A[a]	7.6 ± 3.9	13.8 ± 9.1	5.4 ± 2.7	10.6 ± 3.4	9.8 ± 5.9
Biolure B	10.8 ± 1.5	10.0 ± 6.2	11.8 ± 2.5	12.8 ± 4.6	9.4 ± 3.1
Biolure C	15.4 ± 4.1	14.6 ± 7.4	12.4 ± 3.0	14.6 ± 2.9	9.2 ± 5.8
Septa (1 μg)	0.4 ± 0.9	–	–	–	–
Septa (10 μg)	4.8 ± 0.8	–	–	–	–
Septa (100 μg)	14.0 ± 5.4	–	–	–	–
PVC–86	4.8 ± 3.1	–	–	–	–
PVC–87	14.0 ± 5.4	–	–	–	–

[a] Letters indicate three different types of Biolure. Biolure C was subsequently used in the operational program.

Table 20. Catches of male spruce budworm moths in 1987 in Multi-pher traps baited with IPS vials (colored by the manufacturer either blue or white), pre-aged for up to 6 weeks in a fume hood. Traps were deployed at Kirkwood in 1987 (n = 5).

		Number (±SD) of moths caught, by number of weeks of pre-aging						
Lure	Dates	1	2	3	4	5	6	Check
white	23–30 June	9.4 ± 6.2	20.8 ± 11.8	20.4 ± 17.0	23.4 ± 8.2	19.8 ± 7.1	12.4 ± 6.0	0.2 ± 0.5
	30 June–7 July	6.4 ± 2.4	11.0 ± 7.5	6.6 ± 7.1	7.8 ± 9.7	3.4 ± 2.4	2.8 ± 1.5	
blue	23–30 June	0.8 ± 1.3	0.6 ± 0.9	0.2 ± 0.5	1.6 ± 1.1	0.8 ± 1.1	–	0
	30 June–7 July	1.2 ± 0.8	1.0 ± 0.7	0.8 ± 1.8	0.4 ± 0.9	0.2 ± 0.4	0.2 ± 0.5	

Table 21. Catches of male spruce budworm moths in 1987 in Multi-pher traps baited with rubber septa loaded with 10 μg of pheromone, pre-aged in a fume hood. Traps were deployed at Kirkwood.

	Number (±SD) of moths caught, by number of weeks of pre-aging						
Dates	1	2	3	4	5	6	Check
23–30 June	2.6 ± 1.9	2.1 ± 1.8	1.4 ± 1.9	1.4 ± 1.3	1.6 ± 1.2	1.9 ± 1.5	0.2 ± 0.5
30 June–7 July	1.3 ± 0.9	3.0 ± 2.8	1.6 ± 1.0	1.2 ± 0.5	1.0 ± 0.9	0.4 ± 0.5	0.6 ± 1.3

Table 22. Catches of male spruce budworm moths in 1988 in Multi-pher traps baited with different types of lure, all pre-aged in a fume hood. Traps were deployed 4–6 July at Black Sturgeon Lake (n = 5). See Figure 8 for a graphical presentation of the data.

	Number (±SD) of moths, by number of weeks of pre-aging			
Lure	1	3	5	7
PVC–87 (0.3%)	56.6 ± 24.6	39.4 ± 17.5	49.8 ± 21.3	42.0 ± 23.8
PVC–88 (0.3%)	72.0 ± 52.9	38.6 ± 33.9	24.2 ± 6.5	33.6 ± 8.6
PVC–88 (0.3%)	12.2 ± 7.7	21.0 ± 8.6	16.4 ± 4.7	15.8 ± 3.6
Biolure–88	103.0 ± 14.0	127.4 ± 43.0	97.6 ± 21.0	91.6 ± 13.3
Septa (10 µg)	200.0 ± 119.6	114.8 ± 30.1	151.8 ± 100.7	98.4 ± 46.9

Table 23. Catches of male spruce budworm moths in 1988 in Multi-pher traps baited with different types of lure, all pre-aged in a fume hood. Traps were deployed 6–14 July at Black Sturgeon Lake (n = 5). See Figure 9 for a graphical presentation of the data.

	Number (±SD) of moths, by number of weeks of pre-aging			
Lure	2	4	6	8
PVC–87 (0.3%)	89.8 ± 42.3	82.0 ± 14.7	102.6 ± 26.9	79.4 ± 41.1
PVC–88 (0.3%)	61.2 ± 39.0	51.4 ± 7.9	47.0 ± 16.2	41.6 ± 8.4
PVC–88 (3.0%)	10.4 ± 7.2	27.8 ± 13.3	19.2 ± 5.1	16.0 ± 2.8
Biolure–88	44.2 ± 11.9	55.6 ± 27.9	53.4 ± 19.6	66.8 ± 12.5
Septa (10 µg)	216.7 ± 95.1	202.0 ± 28.0	151.0 ± 35.4	168.0 ± 51.0

Table 24. Catches of male spruce budworm moths in 1989 in IPS Uni-traps baited with PVC–89 or Biolure–89, pre-aged in a fume hood. Traps were deployed at Kirkwood. See Figure 10 for a graphical presentation of these data combined with those in Table 25.

		Number (±SD) of moths caught, by number of weeks of pre-aging				
Lure	Dates	1	2	3	4	5
PVC–89	26 June–6 July	11.0 ± 7.0	10.4 ± 5.7	8.2 ± 6.4	4.2 ± 4.9	–
	6–10 July	–	5.2 ± 3.1	5.6 ± 5.3	4.0 ± 4.3	1.4 ± 0.9
Biolure	26 June–6 July	3.5 ± 1.3	2.8 ± 3.1	2.4 ± 1.1	2.0 ± 1.2	–
	6–10 July	–	2.6 ± 3.2	2.0 ± 0.8	0.6 ± 0.9	0.8 ± 0.8
check	26 June–6 July	0.2 ± 0.4	–	–	–	–
	6–10 July	0	–	–	–	–

Table 25. Catches of male spruce budworm moths in 1989 in IPS Uni-traps baited with PVC or Biolures, pre-aged in a fume hood. Traps were deployed at Black Sturgeon Lake. See Figure 10 for a graphical presentation of these data combined with those in Table 24.

		Number (±SD) of moths, by number of weeks of pre-aging				
Lure	Dates	1	2	3	4	5
PVC–89	7–11 July	45.4 ± 13.2	57.8 ± 13.9	55.2 ± 11.5	49.4 ± 17.0	–
	11–18 July	–	150.6 ± 69.0	153.0 ± 17.4	145.6 ± 28.1	126.4 ± 21.4
Biolure	7–11 July	25.0 ± 9.8	37.0 ± 8.9	31.6 ± 10.4	26.2 ± 6.8	–
	11–18 July	–	107.8 ± 40.9	101.2 ± 16.2	96.8 ± 31.7	94.2 ± 27.8
check	7–11 July	1.8 ± 1.6	–	–	–	–
	11–18 July	14.2 ± 7.9	–	–	–	–

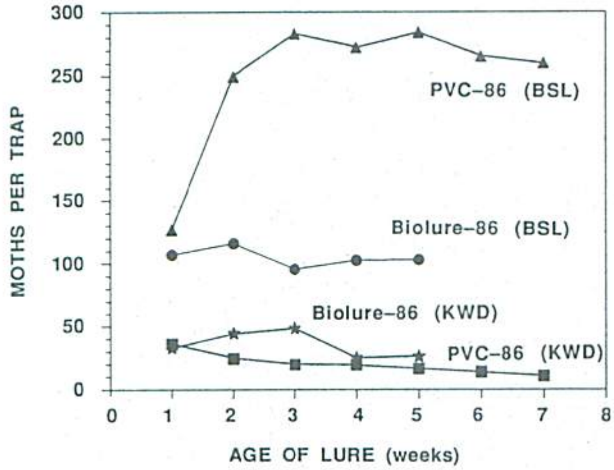


Figure 6. Catches of male spruce budworm moths in 1986 in traps baited with PVC (0.03% w/w) or Biolure (C) lures manufactured in 1986 and pre-aged for various lengths of time. (See Tables 16 and 17 for error estimates.)

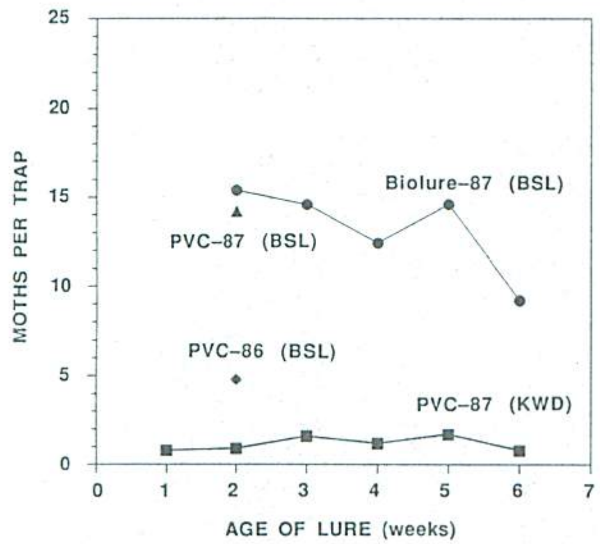


Figure 7. Catches of male spruce budworm moths in 1987 in traps baited with PVC (0.03% w/w) lures manufactured in 1986 and 1987, and Biolures manufactured in 1987, pre-aged for various lengths of time. (PVC–87 = at Kirkwood; all others = at Black Sturgeon Lake.)

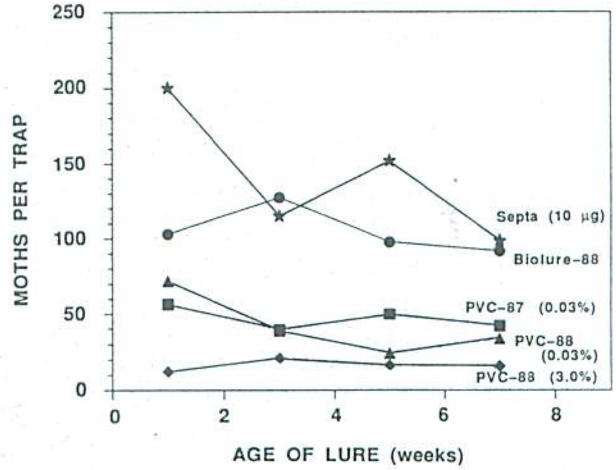


Figure 8. Catches of male spruce budworm moths in 1988 in traps baited with PVC (0.03% w/w) lures manufactured in 1987, PVC (0.03 and 3.0%) manufactured in 1988, Biolures manufactured in 1988, and septa loaded with 10 µg of pheromone. All lures were pre-aged for 1 to 7 weeks. (See Table 22 for standard deviations.)

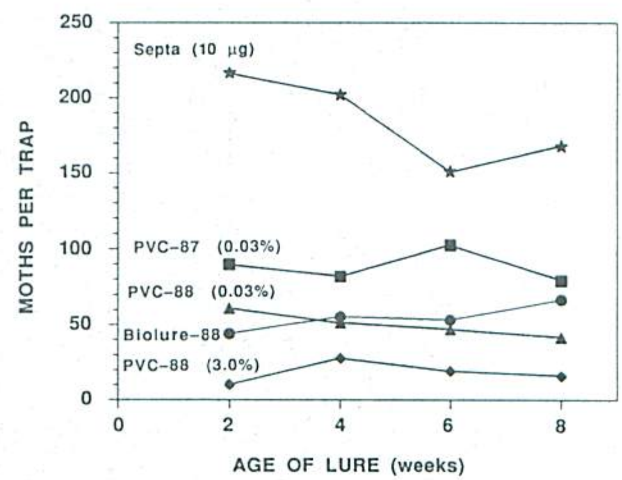


Figure 9. Catches of male spruce budworm in 1988 in traps baited with PVC (0.3% w/w) or Biolures during the second week of the experiment. (See Table 23 for standard deviations.)

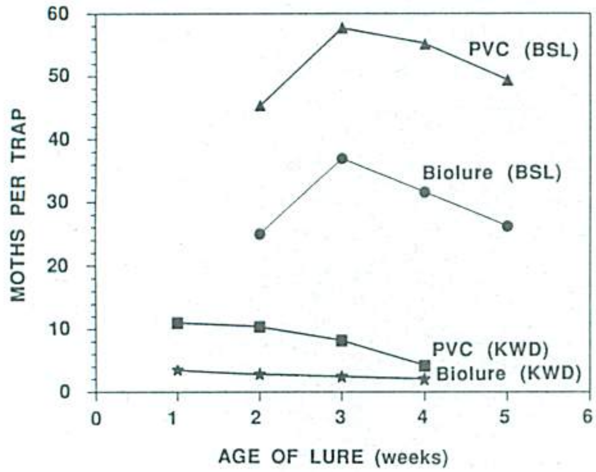


Figure 10. Catches of male spruce budworm in 1989 in traps baited with PVC (0.03% w/w) or Biolures manufactured in 1989, pre-aged for 1 to 5 weeks. (See Tables 24 and 25 for standard deviations.) BSL = Black Sturgeon Lake, KWD = Kirkwood.

In 1988, there was concern among the operational users over the number of zero counts that occurred at very low population densities. It was therefore decided to use a higher release rate than 20 to 40 ng/hour. This justified the use of the Biolures, and starting with the 1989 program, Biolures loaded with 2.8 mg of the pheromone blend have been used in the operational monitoring program. Release rates determined by weight loss from Biolures with an initial loading of 3 mg have been provided by Consep Membrane (Fig. 11). Estimates of the release rates from lures loaded with 2.8 mg of pheromone that were used operationally in 1989, 1990 and 1991 were obtained by T.E. Bellas (Division of Entomology, CSIRO, Canberra) by measuring the active material captured in a stream of nitrogen passing over the lures (Fig. 12). Both sets of data indicate that Biolures have a relatively constant release rate over time. However, the Consep data indicate a loss over the first 60 days of approximately 1.2 µg/day (830 ng/hour), whereas the data from Bellas indicate a release rate of only 50 to 150 ng/hour. The slightly higher initial loading in the lures evaluated by Consep is not sufficient to explain this difference. Possibly the loss of weight recorded by Consep was due in part to loss of non-pheromone compounds from the lures. The direct measurement carried out by Bellas is the more appropriate technique, and the data in Figure 12 are assumed to be accurate estimates of

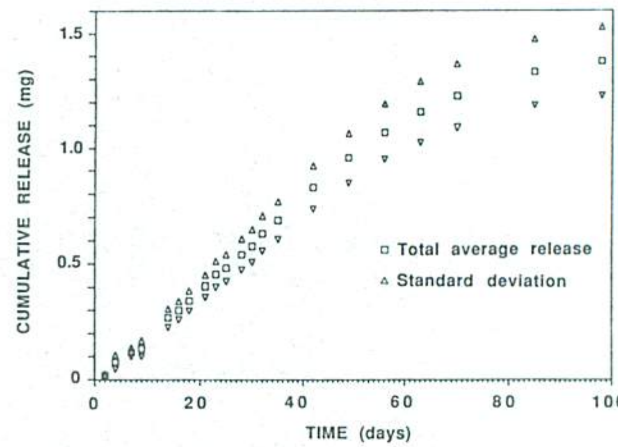


Figure 11. Cumulative amount of 95:5 E– and Z–11–tetradecenal released from Biolures, as determined by weight loss. Initial pheromone loading was 3 mg. Wind speed was 0.3 m/sec, temperature 25°C, and relative humidity 25 to 35%. (Data provided by Consep Membranes Inc., Bend, OR.)

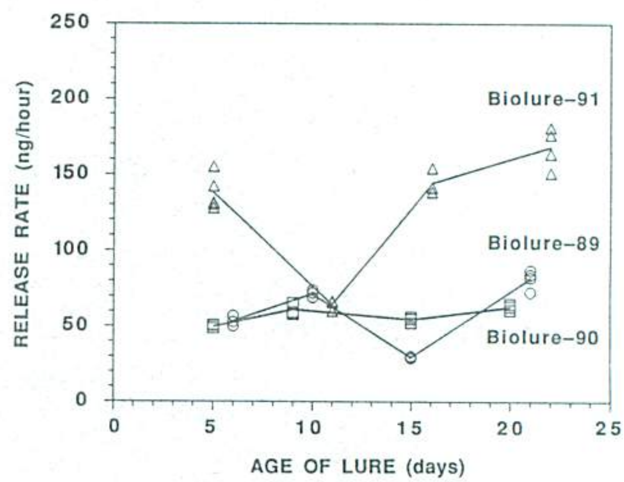


Figure 12. Release rates from Biolures manufactured in 1989, 1990 and 1991, determined by T.E. Bellas (Division of Entomology, CSIRO, Canberra) at 24.4 ± 0.1°C, N_2 gas flow at 58.0 to 62.3 mL/min.

the release rates. It is evident from Figure 12 that release rates from these lures may vary from year to year despite reassurances from the manufacturer that the same technology has been applied each year.

In 1988, Biolures and 0.03% PVC manufactured by RPC in 1988, together with rubber septa loaded with 10 µg of pheromone, were aged for up to 8 weeks in a laboratory fume hood and then deployed in low- and high-density populations. The results are shown in Tables 22 and 23, and graphically in Figures 8 and 9. The results conflicted. During the first week of the experiment, the ranking (number of moths) was septa > Biolure > PVC–88 (0.03%) = PVC–87 (0.03%) > PVC–88 (3.0%). However, in the second week, the ranking was septa > PVC–87 (0.03%) > PVC–88 (0.03%) = Biolure > PVC–88 (3.0%). Moreover, PVC–88 showed a marked decline in potency from week 1 to week 2, but the PVC–87 showed no loss in potency over time. Release rates were recorded from the different batches of lures (Table 14, Fig. 5), but no reasons for these discrepancies could be found.

Additional trials were therefore carried out in 1989 to compare the potencies of Biolure–88 and Biolure–89 with those of PVC–87, PVC–88 and PVC–89 (0.03%). The results (Table 26) indicated that although the potencies of PVC–87 and PVC–88 were similar, PVC–89 lures were far more potent. Furthermore, Biolure–89 was less potent than Biolure–88.

Biolures and PVC were compared in greater detail in Ontario and Newfoundland in 1989. In Ontario, three traps baited with Biolure–89, three with PVC–89 and three unbaited check traps were deployed in 22 plots, covering a range of population densities. The results (Fig. 13) showed an excellent correlation between catches with Biolures and PVC, although the PVC lures were more potent, confirming previous results (Table 26). The relationship between catches in baited and unbaited traps was weak. Possibly the unbaited traps were contaminated with pheromone from previous usage, but unfortunately no record had been kept of the previous usage. In Newfoundland, three traps baited with Biolure–89 and three with PVC–89 were deployed at nine locations. Again, the correlation between the two was good (Fig. 14), but in contrast to the Ontario data, the Biolures were slightly more potent than the PVC. There is no obvious explanation for this.

In connection with other experiments on spruce budworm moth behavior in 1989, comparisons were also made among three different concentrations of PVC–89 (0.03, 0.3 and 3.0% w/w; Table 27). At low population densities, the sequence was as expected: 3.0 > 0.3 > 0.03. However, at high densities the trend was reversed. A similar result was obtained in experiments with PVC lures during comparisons with virgin female moths in 1979 (Fig. 15). There is no obvious reason for this, except possibly that the high-potency lures were repellent, although it is not clear why this should happen at high densities but not at low densities.

Table 26. Catches of male spruce budworm moths in 1989 in traps baited with PVC–87, PVC–88, PVC–89, Biolure–88, or Biolure–89: at Kirkwood, in Pherocon–1CP traps (n = 9) deployed 30 June–16 July 1989; at Black Sturgeon Lake, in Multi-pher traps (n = 5) deployed 21 July–16 August 1989.

	Number (±SD) of moths caught	
Lure	Low density (Kirkwood)	High density (Black Sturgeon Lake)
PVC–87 (0.03%)	26.3 ± 8.2	–
PVC–88 (0.03%)	21.1 ± 12.0	–
PVC–89 (0.03%)	155.7 ± 31.7	–
Biolure–88	153.5 ± 31.8	67.9 ± 11.5
Biolure–89	154.1 ± 34.1	17.3 ± 6.2
Check (unbaited)	0.1 ± 0.3	–

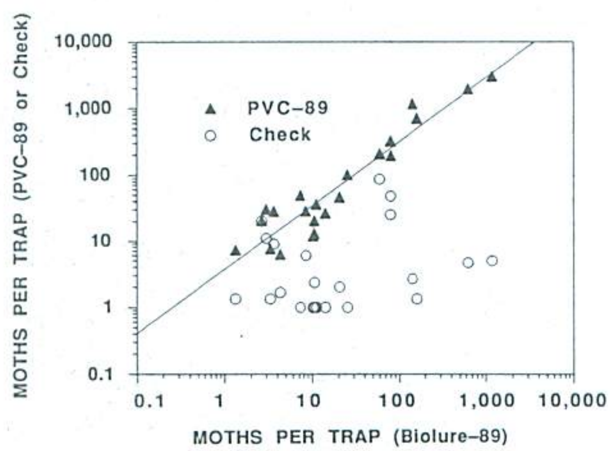


Figure 13. The relationship between catches in clusters of three traps baited with PVC (0.03% w/w) manufactured in 1989, with Biolures manufactured in 1989, and for unbaited check traps, deployed in 22 plots covering a wide range of population densities in northern Ontario in 1989. Line represents the following regression: Log(PVC+1) = 0.58 + 0.96log(Biolure+1), r^2=0.89, t=12.5 (df=20)

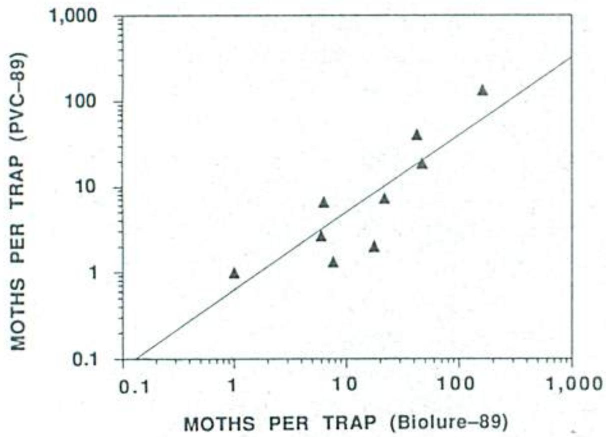


Figure 14. The relationship between catches in clusters of three traps baited with PVC (0.03% w/w) and clusters baited with Biolures manufactured in 1989 from nine plots in Newfoundland (Data provided by A. Raske (Forestry Canada, Newfoundland and Labrador Region, St. John's, Nfld.). Line represents the following regression: Log(PVC+1) = –0.20 + 0.90log(Biolure+1), r^2 =0.78, t=5.34 (df=8)

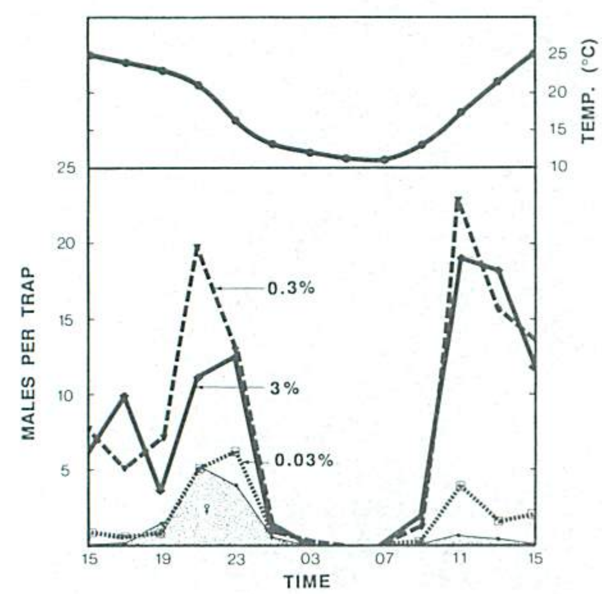


Figure 15. Catches of male spruce budworm moths recorded every 2 hours over a 24-hour period in Pherocon 1C traps baited with PVC lures manufactured in 1979 (at 3 concentrations) compared with catches by virgin female moths (shaded area) in a high-density population near Sault Ste. Marie in 1979.

Table 27. Catches of male spruce budworm in 1989 in Multi-pher traps baited with PVC–89 (0.03, 0.3 or 3.0% w/w pheromone) and Biolure–89 pinned or stuck with adhesive tape inside the top of the traps. Traps were deployed at Kirkwood 30 June–16 July 1989 (n = 9) and at Black Sturgeon Lake 7–13 July 1989.

		Number (±SD) of moths caught	
Lure		Low density (Kirkwood) (n = 9)	High density (Black Sturgeon Lake) (n = 5)
PVC–89	0.03%	6.3 ± 3.4	66.0 ± 18.8
	0.3%	11.4 ± 5.8	44.0 ± 19.5
	3.0%	18.2 ± 9.0	31.4 ± 6.0
Biolure	pinned	1.4 ± 0.9	44.0 ± 22.2
	adhesive	2.1 ± 2.4	33.0 ± 20.1
Check (unbaited)		0	4.6 ± 5.0

Questions have also arisen about the methods of attaching Biolures inside the traps. Starting with the use of PVC formulations, the lures were pinned to the roof of the traps, but the Biolures are provided with a sticky backing that can be used to stick them to the roof of the trap. Comparisons indicated no significant differences in the numbers of moths caught between lures pinned or stuck to the roof (Table 27). However, lures that have been stuck to the inside of the trap frequently fall off while deployed in the field throughout the flight period of the spruce budworm. It is therefore recommended that the lures be pinned or taped to the top of the trap. Care must be taken to ensure that the plastic "bubble" in the center of the lure (which contains the formulated pheromone) is not punctured or covered.

In 1990, Biolure–88, Biolure–89 and Biolure–90 were compared in both low- and high-density populations (Table 13). Catches with Biolure–89 and Biolure–90 were very similar. This was demonstrated more convincingly in a series of plots spanning a wide range of population densities in northern Ontario, in which three traps containing Biolure–89 and three containing Biolure–90 were deployed. The results (Fig. 16) showed that the lures were very similar in potency and that catches in the monitoring program in 1989 and 1990 using these Biolures were probably quite comparable. Catches with Biolure–88 were far higher than with Biolure–89 or Biolure–90 (Table 13), but, because the latter were not used operationally in the monitoring program in 1988, this does not present a problem. However, it does indicate that serious differences in potency can occur with commercial lures.

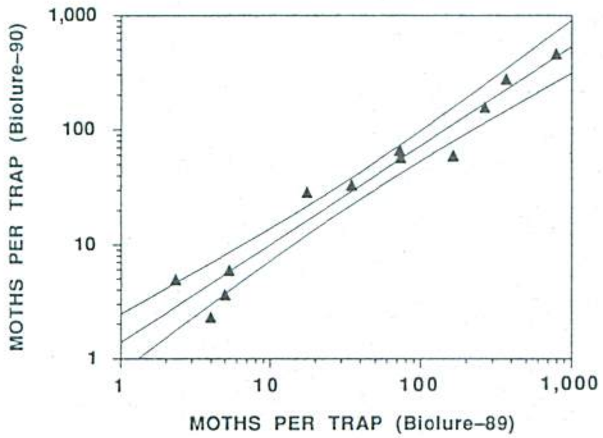


Figure 16. The relationship between catches in clusters of three traps baited with Biolures manufactured in 1990 and in clusters of three traps baited with Biolures manufactured in 1989 in 12 plots in northern Ontario, 1990. Inner line represents the following regression: Log(Biolure–90) = 0.14 + 0.86log(Biolure–89), $r^2=0.95$, $t=13.45$ (df=10). Outer lines represent 95% confidence limits.

In 1991, comparisons were made between Biolure–89, Biolure–90 and Biolure–91 in both low- and high-density populations (Table 28). Catches with Biolure–89 and Biolure–90 were comparable, confirming the 1990 results, but catches with the Biolure–91 were five times as high. These differences in potency may have been due to differences in the pheromone blend and/or the release rate. Although data on the quality of the pheromone used for formulating the lures are not available for every year of the program, they are available for the Biolures manufactured from 1988 through 1991. Gas chromatograms for these are shown in Figures 17 through 20. The purity of the samples (expressed as % aldehyde component) and the *E*:*Z*–ratios of the aldehydes for each year are shown in Table 29.

In addition to the gas chromatography data on the material before it was formulated, release rates and the *E*:*Z*–isomer ratios emitted by the Biolure–89, Biolure–90 and Biolure–91 lures were measured by T.E. Bellas (Division of Entomology, CSIRO, Canberra). The results are summarized in Table 30 and the release rates are shown graphically in Figure 12. The *E*:*Z* ratio of the material emitted from Biolure–91 was close to 93:7, compared with the ratio of 94.5:5.5 in the material before it was formulated (Table 29). These

Table 28. Catches of male spruce budworm moths in 1991 in Multi-pher traps baited with Biolure–89, Biolure–90, and Biolure–91. Traps were deployed at Kirkwood 20 June–9 July (n = 5); at Black Sturgeon Lake, traps were deployed 24–29 June (n = 5).

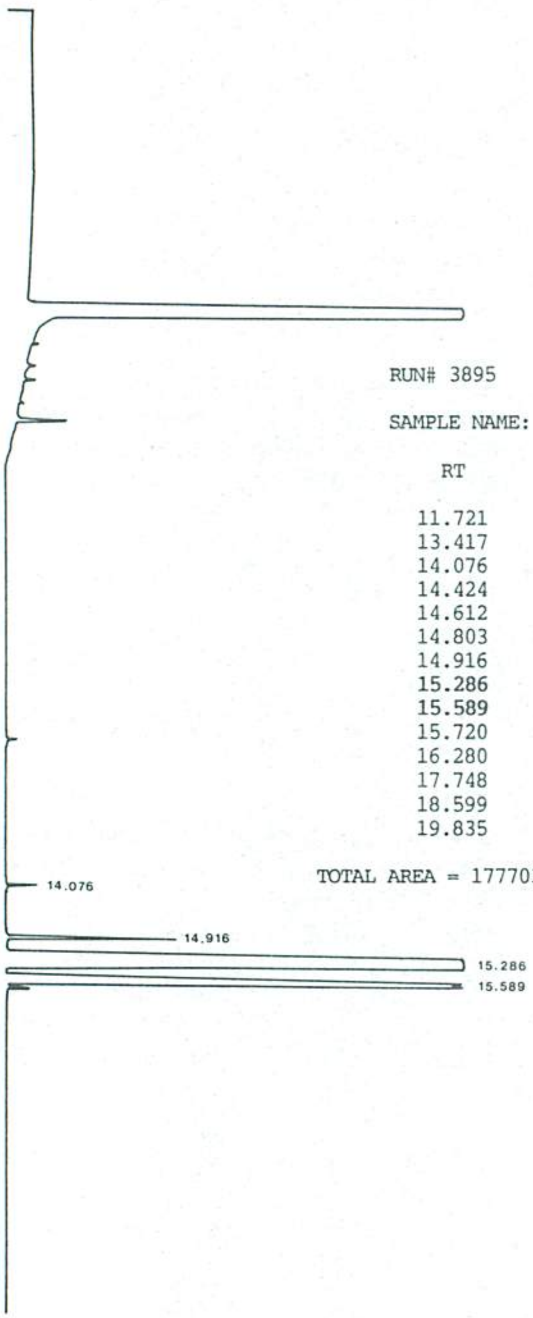
	Number (±SD) of moths caught	
Lure	Low density (Kirkwood)	High density (Black Sturgeon Lake)
Biolure–89	1.8 ± 1.8	57.0 ± 14.1
Biolure–90	0	43.2 ± 13.6
Biolure–91	9.4 ± 4.6	289.8 ± 87.4
Check (unbaited)	0.2 ± 0.4	15.0 ± 6.0

Table 29. Purity and E:Z isomer ratios of material formulated in Biolure–88, Biolure–89, Biolure–90 and Biolure–91, as determined by Consep Membranes Inc. before the material was formulated.

Year	Purity (aldehyde as % total)	*E*:*Z* isomer ratio
1988	94.7	93.1 : 6.8
1989	90.2	97.9 : 2.1
1990	92.7	91.8 : 8.2
1991	97.5	94.5 : 5.5

Table 30. Release rates and percentages of the Z–isomer (both ±SD) emitted by Biolure–89, Biolure–90 and Biolure–91, as determined by T. Bellas (Division of Entomology, CSIRO, Canberra).

Lure	Day	Release rate (ng/hour)	Z–isomer (% of total)
Biolure–89	6	53.4 ± 3.0	13.1 ± 1.0
	10	71.4 ± 1.8	9.4 ± 2.3
	16	29.4 ± 0.6	–
	22	81.6 ± 5.4	12.6 ± 1.3
Biolure–90	5	49.8 ± 0.6	12.9 ± 0.4
	9	61.2 ± 3.0	13.0 ± 0.5
	15	54.6 ± 1.2	12.1 ± 0.7
	20	63.0 ± 1.2	11.8 ± 0.2
Biolure–91	5	137.4 ± 10.2	6.1 ± 1.5
	11	64.2 ± 3.0	9.7 ± 0.6
	16	144.6 ± 6.6	–
	22	168.0 ± 412.0	5.7 ± 1.8



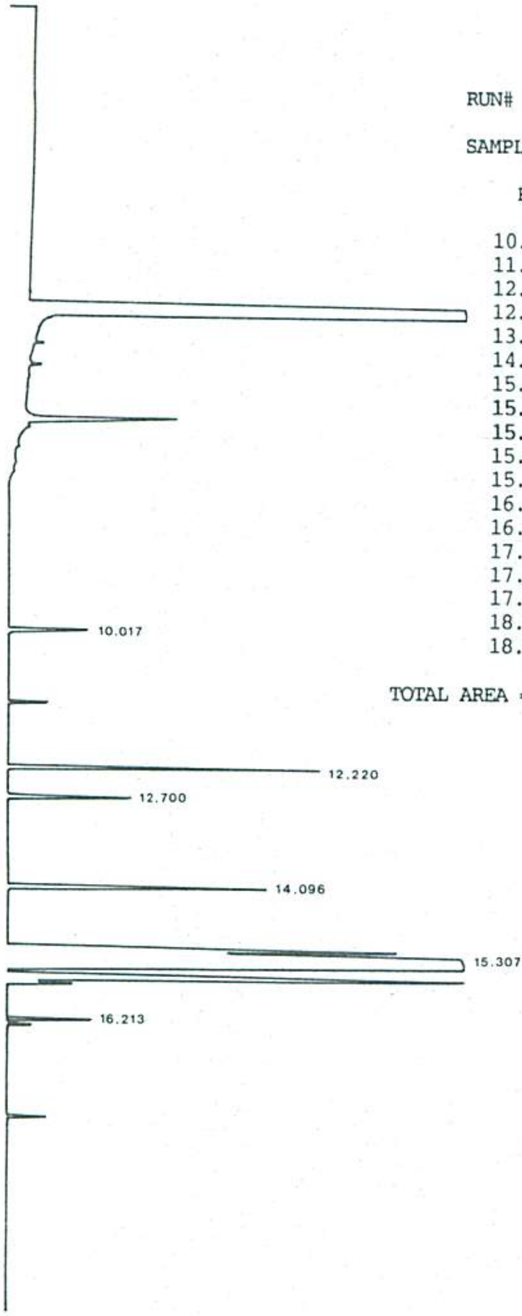
RUN# 3895 NOV 18, 1989 17:32:08

SAMPLE NAME: ESBW FROM PS SAMPLE# 33

RT	AREA	TYPE	WIDTH	AREA%
11.721	13687	BP	.094	.77021
13.417	3004	PP	.054	.16905
14.076	11696	BB	.055	.65817
14.424	2325	PV	.061	.13084
14.612	11749	VV	.106	.66116
14.803	8555	VV	.061	.48142
14.916	21147	VP	.060	1.19001
15.286	1565963	PB	.099	88.12205
15.589	116623	BV	.069	6.56277
15.720	6548	VB	.049	.36848
16.280	3563	PV	.065	.20050
17.748	7522	PB	.063	.42329
18.599	4163	PV	.150	.23427
19.835	494	PV	.127	.02780

TOTAL AREA = 1777039

Figure 17. Gas chromatogram for the pheromone used to manufacture Biolures in 1988. Purity of aldehydes = 94.7%, isomer ratio = 93.1 E:6.9 Z. (Chromatogram provided by Consep Membranes Inc., SP 2340 column.)



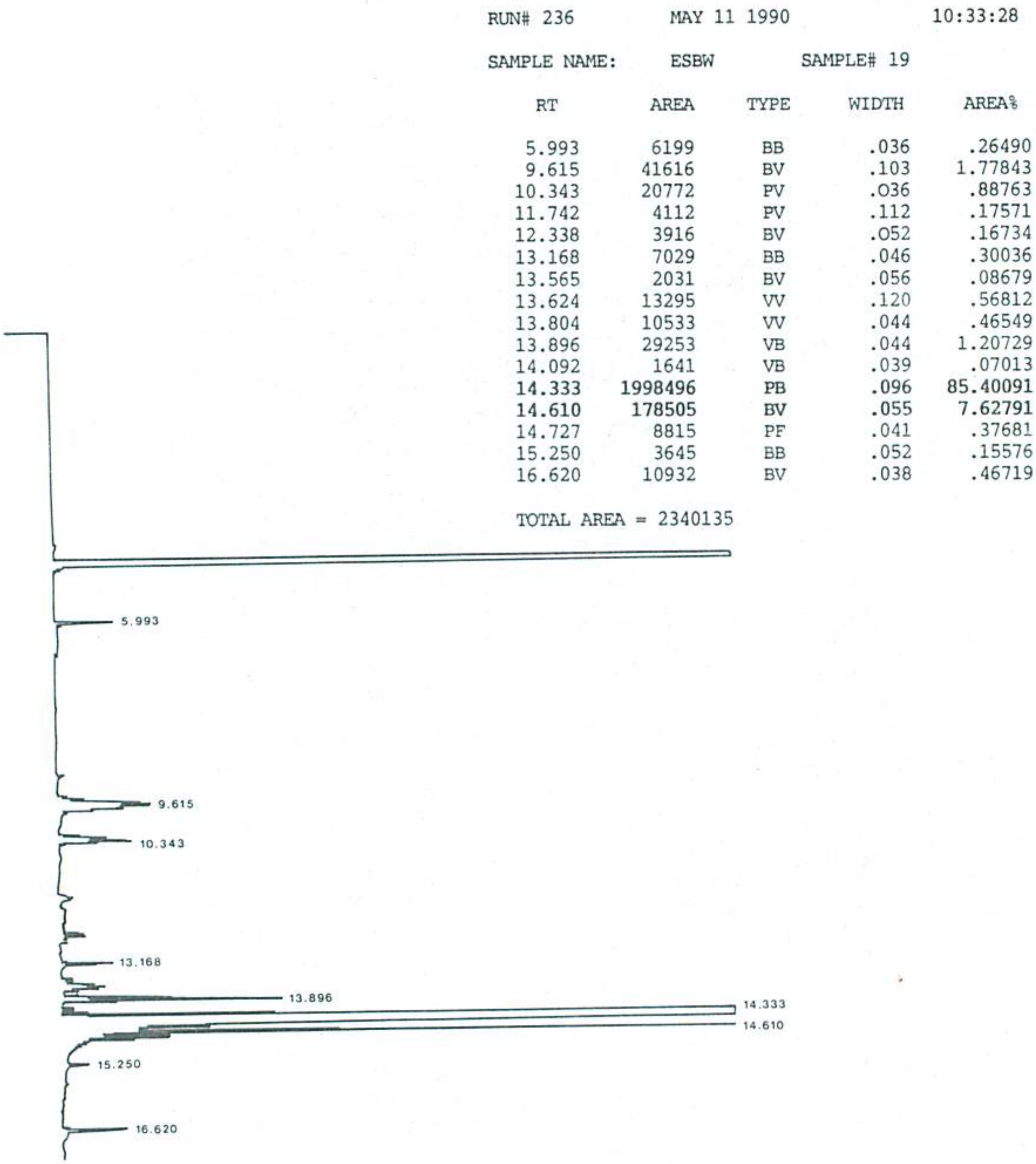
RUN# 3093 NOV 10, 1989 16:43:30

SAMPLE NAME: E-11 TETRADE SAMPLE# 31

RT	AREA	TYPE	WIDTH	AREA%
10.017	6816	PB	.049	.38280
11.171	6875	VB	.056	.38612
12.220	23243	BB	.051	1.30539
12.700	21337	VP	.083	1.19834
13.635	1778	PP	.054	.09986
14.096	23538	PB	.057	1.32195
15.089	33405	PV	.064	1.87611
15.307	1571964	VB	.099	88.28557
15.534	33620	BV	.054	1.83819
15.620	7344	VP	.055	.41246
15.978	1691	VP	.081	.15113
16.213	12249	PV	.062	.68794
16.305	9183	VB	.072	.51574
17.435	2321	VV	.037	.13035
17.570	2803	VV	.109	.15742
17.777	11588	VV	.085	.65081
18.496	6138	VV	.122	.34473
18.902	3653	VV	.120	.20511

TOTAL AREA = 1780545

Figure 18. Gas chromatogram of material provided by the New Brunswick Research Productivity Council (synthesized by B. Lynch, Chemistry Department, St. Frances Xavier Univ., Halifax, Nova Scotia) and used to manufacture Biolures in 1989. Purity = 90.2% aldehyde, isomer ratio = 97.9 E*:2.1* Z*. (Chromatogram provided by Consep Membranes Inc., SP 2340 column.)*



RUN# 236 MAY 11 1990 10:33:28

SAMPLE NAME: ESBW SAMPLE# 19

RT	AREA	TYPE	WIDTH	AREA%
5.993	6199	BB	.036	.26490
9.615	41616	BV	.103	1.77843
10.343	20772	PV	.036	.88763
11.742	4112	PV	.112	.17571
12.338	3916	BV	.052	.16734
13.168	7029	BB	.046	.30036
13.565	2031	BV	.056	.08679
13.624	13295	VV	.120	.56812
13.804	10533	VV	.044	.46549
13.896	29253	VB	.044	1.20729
14.092	1641	VB	.039	.07013
14.333	1998496	PB	.096	85.40091
14.610	178505	BV	.055	7.62791
14.727	8815	PF	.041	.37681
15.250	3645	BB	.052	.15576
16.620	10932	BV	.038	.46719

TOTAL AREA = 2340135

Figure 19. Gas chromatogram of material synthesized by Orsynex (Columbus, OH; Lot 108–43JKS) and used to manufacture Biolures in 1990. Purity = 92.7% aldehyde, isomer ratio = 91.8 E*:8.2* Z*. (Chromatogram provided by Consep Membranes Inc., SP 2340 column.)*

RUN# 662 MAY 1, 1991 12:02:31

SAMPLE# 1

SPRUCE BUDWORM, 1:1 IN HEXANE #585

RT	AREA	TYPE	WIDTH	AREA%
8.754	1938	VP	.224	.06855
11.304	14258	PV	.126	.50432
11.429	17760	VV	.163	.62854
11.658	4785	VV	.089	.16925
11.740	4750	VV	.057	.16801
12.085	378	PV	.044	.01337
12.170	530	VP	.043	.01875
12.635	392	BV	.035	.01387
12.832	4199	PV	.044	.14852
13.051	4293	VP	.076	.15185
13.793	**2605773**	**PB**	**.092**	**92.16896**
13.973	6357	BV	.034	.22485
14.041	**150450**	**VB**	**.044**	**5.32158**
14.252	1184	BV	.039	.04188
14.389	1553	VP	.070	.05493
14.680	1291	PP	.061	.04566
14.850	2083	PV	.046	.07368
15.588	2137	BV	.052	.07559
15.696	1335	VV	.048	.04722
16.013	584	PV	.066	.02066
20.634	1129	BP	.072	.03993

TOTAL AREA = 2827168

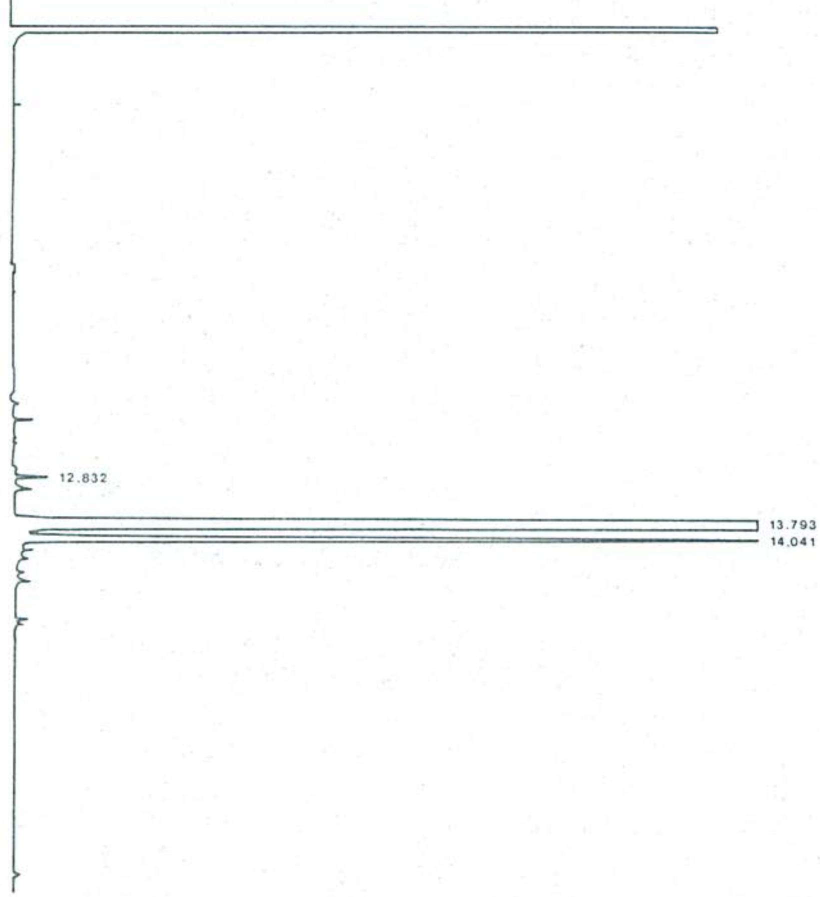


Figure 20. Gas chromatogram of pheromone obtained from G.E. Daterman (USDA Forest Service, Corvallis, OR; Lot #585) and used to manufacture Biolures in 1991. Purity = 97.5% aldehyde, isomer ratio = 94.5 E:5.5 Z. (Chromatogram provided by Consep Membranes Inc., SP 2340 column.)

numbers are well within the range from 99:1 to 90:10, which is the range of optimum potency (Sanders and Weatherston 1976, Silk et al. 1980). The *E*:*Z* ratios of the material emitted from Biolure–89 and Biolure–90, however, were on the order of 88:12. These differ considerably from the ratios recorded by Consep Membranes Inc. in the material before it was formulated (Table 29). It is unlikely that the emission rates of the two isomers differ significantly, and there is no obvious explanation for these discrepancies. However, the emitted ratios for both years (Table 30) are outside the optimal range, suggesting there would have been some loss in potency. Biolure–91 was found to have a release rate about twice those of Biolure–89 and Biolure–90, averaging 129 ng/hour compared with 59 and 57 ng/hour, respectively.

Results from the trap-catch data in the previous section indicate relative potencies as follows: Biolure–91 = Biolure–88 > Biolure–89 = Biolure–90. The isomer ratios of the 1991 and 1988 material before formulation, and of the released 1991 material, were closest to the 96:4 ratio of the natural pheromone (Sanders and Weatherston 1976, Silk et al. 1980). The samples were also of higher purity, and in the case of the 1991 lures, had higher release rates. Biolure–89 and Biolure–90, in contrast, contained an *E*:*Z* isomer ratio considerably different from the natural blend, a release rate about half that of the 1991 lures, and considerable impurities. Although it is relatively easy to monitor *E*:*Z* ratios and overall purity, it is very difficult to identify the impurities and to determine which are behaviorally important. It is becoming evident for many Lepidoptera that pheromone blends may include minor components that have profound biological effects. The budworms are no exceptions (Sanders 1984a) and it is possible that one or more of the impurities in Biolure–89 and Biolure–90 were biologically active. The only compounds that are known to have an inhibitory effect are Δ–11–tetradecenyl acetate and Δ–11–tetradecenol (Sanders 1976, 1990a). Specifications have always included the stipulation that samples of the aldehydes must contain neither of these compounds, and within the detection limits of the equipment, no trace of either has been found in any of the samples. The lower potencies of Biolure–89 and Biolure–90 were probably due to a combination of factors, including impure materials, off-blends, and lower release rates. Given the available evidence, it is essential to ensure that the material used for monitoring spruce budworm contains no Δ–11–tetradecenyl acetate or Δ–11–tetradecenol, and that it has an overall aldehyde purity of greater than 97%, with the *E* isomer between 93 and 96%, and that release rates are constant from year to year.

In order to safeguard against variations from year to year, it is essential that each batch of lures be cross-calibrated against previous batches to provide comparable catch data from year to year. Available comparisons for the years 1986 through 1989 are presented graphically in Figures 8 through 12. Data on the comparisons between Biolure–88, Biolure–89 and Biolure–90, and between Biolure–89, Biolure–90 and Biolure–91, are shown in Tables 13 and 28.

In most cases, these data have proven inadequate for reliable correction factors to be applied to the trap catches. The exception is Figure 16, in which comparisons were made over a wide range of population densities. This provided a regression that can be applied as a correction factor to the trap-catch data. In future, for all species and not just the spruce budworm, this type of data is essential in order to be sure that data are comparable from year to year.

Conclusion

Biolures provide a constant release rate at a level that results in a useful range of catches. They should be suitable for the spruce budworm monitoring program if differences in potency from year to year can be resolved. It is probable that these differences are due to a combination of factors: differences in pheromone blend, in release rate, and in purity. These problems can be avoided by obtaining a stockpile of suitably pure pheromone and manufacturing lures with material from this same source each year. To ensure that lures are of equal potency, and to provide a correction factor if they are not, it is absolutely essential that cross-calibration (as shown in Figure 16) be carried out each year over a wide range of population densities.

SUMMARY OF THE CURRENT STATUS OF TRAPS AND LURES

Trap design

The currently recommended trap is the Mult-pher-I (Le Groupe Biocontrôle, 2600 Rue Dalton, Ste-Foy, Que. G1P 3S4). The recommended insecticide formulation for use in the traps is the Vaportape II (Hercon Environmental Co., Aberdeen Road, Emigsville, PA, 17318, obtainable in Canada from Le Group Biocontrôle). This should be dropped to the bottom of the trap bucket.

Future research needs are to identify or develop an inexpensive disposable trap to avoid problems of trap contamination and to remove the need for storage.

Lure

The currently recommended lure is the Biolure (Consep Membranes Inc., 213 SW Columbia, Bend, OR, 97708) loaded with 2.8 mg of 95:5 *E*:*Z*–tetradecenal. The pheromone should have an overall purity of at least 97% aldehydes and contain no Δ–11–tetradecenyl acetate or Δ–11–tetradecenol. Lures should be pinned or taped to the underside of the trap's lid.

A supply of high-quality pheromone stock material is required to ensure a continuous supply of known purity.

Trap deployment

At each location, three traps should be deployed in a triangular layout 40 m apart with none of them closer to the edge of the stand than 40 m. Traps should be hung on a dead limb of a host tree at head height (1.5 to 2.0 m). Traps should be deployed about a week before the anticipated start of moth flight and should be collected well after the end of local moth flight to allow for possible immigration of moths from areas in which insect development was slower.

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