



## The relative performance of pheromone and light traps in monitoring the seasonal activity of both sexes of the eastern hemlock looper, *Lambdina fiscellaria fiscellaria*

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### Abstract

The seasonal flight activity of both sexes of the eastern hemlock looper, *Lambdina fiscellaria fiscellaria* Guenée (Lepidoptera: Geometridae) was studied during two consecutive years in Quebec and Newfoundland, using light (L), pheromone (P) and combined light and pheromone (LP) traps. Moth density significantly affected the performance of the different traps, with P traps being more effective at low than high density. However, P trap catches decreased just prior to the onset of female captures, probably as a result of competition between traps and virgin calling females. Nearly all females caught in L and LP traps were already mated and even the first females caught had laid at least half of their egg complement. In Quebec under warm nights, the pattern of male activity occurred at different times, with peak P catches being later in the scotophase than those of L traps, but overall similar numbers of males were caught in both traps. In contrast, under cool nights, males were caught early in the night in both P and L traps, suggesting a strong competition effect between traps, although more males were caught in P than L traps overall. In Newfoundland, the pattern of male captures in L and P traps was similar at both high and low temperatures, so competition between trap types would always be high. Under these conditions P traps were more effective than L traps. Irrespective of the region, year or temperature, significantly more males were captured in LP, with the effect of L and P being additive. In both regions, females responded similarly to L and LP traps with peak activity occurring early in the night. Captures of females were lower than those of males under cool temperatures, suggesting that the temperature threshold for flight is higher for females. The use of L and P traps simultaneously and/or in combination is discussed in relation to integrated pest management programs and ecological considerations.

### Introduction

The interpretation of trap capture data for flying insects is often difficult as numerous factors may directly or indirectly affect the behavioral response of males and females to the different stimuli used. Obviously, the physical characteristics of the trap or the trapping system are important, but errors may also occur as a result of environmental and/or climatic conditions prevailing at the time of sampling (for a general

review see Muirhead-Thomson, 1991). One way to improve trap interpretation is the simultaneous use of several sampling methods (Oloumi-Sadeghi et al., 1975). However, this may be very costly with respect to handling time, thereby making the potential of such an approach rather low.

When given the choice between different trapping techniques for moth species, pheromone traps have generally been preferred to light traps as they are more species-specific, and thus less labor intensive, they

are usually less expensive, and as they do not require a power source they have greater flexibility with respect to trap location (Srivastava & Srivastava, 1989). However, light traps have proved a valuable technique because they attract both sexes of some species. Furthermore, the use of both types of traps simultaneously may help in interpreting pheromone trap catches because the reproductive state of the females caught in light traps may provide some insight into competition between pheromone traps and feral females (Gentry & Davis, 1973; Hendricks et al., 1973; Oloumi-Sadeghi et al., 1975; Fletcher-Howell et al., 1983; Dent & Pawar, 1988; Srivastava & Srivastava, 1989; Herbert et al., 1991; Campbell et al., 1992). However, using different trapping techniques simultaneously may also lead to additional sources of error in the interpretation of trap catches, because of potential interference between traps (Bucher & Bracken, 1979) or confounding effects of environmental conditions on insect activity patterns (Dent & Pawar, 1988).

Jobin & Coulombe (1992) recently developed the Luminoc<sup>®</sup> trap, which is a miniaturized, portable insect light trap equipped with a 6 volt battery activated by a photocell and a time clock. This trap not only facilitates the sampling of both sexes but can be used for monitoring forest pests where light traps have been used less frequently than in agriculture due to problems with the availability of power sources. Furthermore, the substantial increase in male trap catches reported when virgin females and/or synthetic lures were placed in the vicinity of the light traps (Hoffman et al., 1966; Henneberry & Howland, 1966; Henneberry et al., 1967; Hendricks, 1968; Haile et al., 1973; Gentry & Davis, 1973) suggests that the combination of both attractants might be an effective tool for mass trapping.

Following the commercial availability of the Luminoc<sup>®</sup> trap and the recent identification of the female sex pheromone of the eastern hemlock looper (EHL), *Lambdina fiscellaria fiscellaria* (Gries et al., 1991), a major pest on balsam fir, *Abies balsamea* (L.) Miller, and eastern hemlock, *Tsuga canadensis* (L.), in eastern North America (Otvos et al., 1979), we undertook a two-year project to study the potential of combined trapping. This study was carried out simultaneously in Quebec and Newfoundland (Canada) to determine how population density, as well as abiotic variables and geographical differences, may influence the behavioral response of both sexes to light (L), pheromone (P), and combined light and pheromone (LP) traps. Seasonal changes in trap performance were

also examined in relation to mating and oviposition activities of the EHL.

## Materials and methods

The Quebec site was located in the Reserve du Parke, near Kamouraska (47°30' N, 70°30' W) in a mature stand of 70- to 90-year-old balsam fir, severely infested by EHL in 1990 and 1991. In Newfoundland, the 1991 field site was located on the Avalon Peninsula near Flatrock, in a 50- to 90-year-old balsam fir stand, lightly to moderately defoliated by EHL from 1988 to 1991. However, the looper density declined in 1991, so in 1992 the field site was moved to Portugal Cove, in a stand with similar characteristics. Both sites were located near St. John's (47°35' N, 52°42' W). Trials were carried out in 1991 and 1992.

Multi-Pher<sup>®</sup> traps (BIOCOM, Sainte-Foy, Quebec) (Jobin & Coulombe, 1988), with two interlocking pieces of 2 mm × 80 mm × 115 mm plexiglass to intercept flying moths, were used as P traps in all experiments. The L traps, a modification of the Multi-Pher<sup>®</sup> trap, called the Luminoc<sup>®</sup> trap, were equipped with a 5.0 × 0.5 cm fluorescent blue light bulb (wavelength ranging between 300–600 nm) and operated from dusk (19:00) to dawn (05:00). The P trap had the bulb replaced with a red rubber septum (Aldrich Chemical Co., Milwaukee, Wisconsin, USA) impregnated with 25 µg of 5, 11-dimethylheptadecane and 100 µg of 2, 5-dimethylheptadecane, two active components of the EHL female sex pheromone (Gries et al., 1991). The same lures were used throughout the flight period, because they are known to remain active for extended periods (West & Bowers, unpubl. data). In the combined LP trap the lure was placed just beside the light in the funnel. Unbaited traps without the lamp were used as controls (C). A piece of dichlorvos-impregnated wax (Vapor Tape II<sup>®</sup> insecticide strip) (Hercon Laboratories, New Jersey, USA) was placed in the bucket of each trap.

At both sites, each treatment was replicated four times using a Latin square design. In all experiments, traps were suspended 2 m above the ground and spaced 20 m apart. The position of each trap was randomized weekly. Throughout the flight period, at both sites, adult captures were collected daily, so the number of males and females was determined in each trap. Temperature was recorded at 30 min intervals, over the entire flight period, using a 21X data logger (Campbell Scientific, Inc., Edmonton, Alberta, Canada).

Each year, the total trap catches obtained in each treatment during warm and cool nights at the two sites were compared. As EHL activity was generally initiated after dusk, only temperatures recorded from 18:00 to 06:00 were used to determine warm and cool nights. The range of temperature over which moths flew during the flight period varied from 5 to 17 °C in both locations, so 11 °C was used to fix the limit between the two temperature conditions.

The number of individuals per treatment was analyzed separately for sex, site and year. In order to obtain the homogeneity of variance, raw data were log-transformed and then subjected to a two-way ANOVA, using treatment (L, P, LP, C) and temperature (warm and cool nights) as main effects. Orthogonal contrasts were computed to compare the performance of each trap alone, or in combination with temperature. Control traps were not used for these comparisons, because the number of individuals caught was too low (<5%). This analysis was performed using the PROC MIXED procedure of SAS/STAT (SAS Institute, 1990). As the number of females caught in P traps was similar to controls, we present only comparisons of L and LP traps.

In 1992 on several nights, hourly adult captures in each trap of the L, P and LP treatments were also monitored from 18:00 to 06:00 to assess the period of maximal flight activity as a function of prevailing temperature conditions at both sites. As above, the activity of females was compared in L and LP traps only.

Each day the surface area of the right forewing of 20 males and 20 females, chosen at random from each trap for each treatment (or the total number when densities were below this level), was measured using a computerized image analyzer (Wild Leitz, Heerbrugg, Switzerland). This parameter was used as an estimate of body size at the time of emergence. The rest of the body was placed at 50 °C for 24 h and then the dry weight measured on a 200D Sartorius semi-microbalance. The intra- and inter-seasonal variation of both variables were analyzed separately for males and females at both sites using a two-way ANOVA with year (1991 and 1992) and time (1st, 2nd or 3rd week of the flight period), as main effects. Orthogonal contrasts were also performed to assess the linear and quadratic effects of time alone or in combination with years of male and female trap catches. This analysis was performed using the PROC GLM procedure of SAS/STAT (SAS Institute, 1990).

The reproductive state of females was recorded daily for three periods of one week. Each female was

placed in an individual aluminum container and kept for 24 h in a closed plastic box containing hot water. Once softened, females were then dissected and the number of spermatophore(s) present in the bursa copulatrix was determined. Three categories (0, 1 or  $\geq 2$  spermatophores) were used for comparisons. In this species, mating generally occurred on the night following emergence.

In the Quebec population, an estimate of the ovipositional history of feral females caught in L and LP traps during the 1991 and 1992 flights was determined from the linear relationship between dry mass and wing surface area, expressed as a slope ( $m$ ) (Maltais et al., 1989). The slope values obtained for feral moths ( $m_f$ ) caught in L or LP traps were then compared with those for fully-gravid ( $m_g$ ) (100% of egg complement) and spent ( $m_s$ ) (0% of egg complement) females. These were obtained from females collected as pupae at different times in the field, in order to obtain the whole variability in both size and weight of the population. Pupae were reared at 15 °C under a L12:D12 photoperiod. The proportion of eggs laid ( $p$ ) by the captured females as a function of time (week intervals) was determined using the following equation:

$$p = \frac{m_g - m_f}{m_g - m_s}$$

During 1991 in Quebec, the cumulative proportion of eggs laid as a function of time by EHL females, collected as pupae in the field, was determined at three constant temperatures (10, 15 and 20 °C), under a L12: D12 photoperiod. A minimum of 20 mated females were used in each treatment. These curves were subsequently used to approximate the time at which mating occurred and the pattern of oviposition of feral females during both flight periods, based on the estimated proportion of eggs laid by individuals captured in traps.

## Results

In Quebec, the flight period of EHL started in mid-August and was almost completed by the end of September in both years (Figure 1). Males were always captured earlier than females. However, the response of males to the different stimuli varied over the season. At the beginning of the 1991 flight, there were similar numbers of males in P and L traps but captures

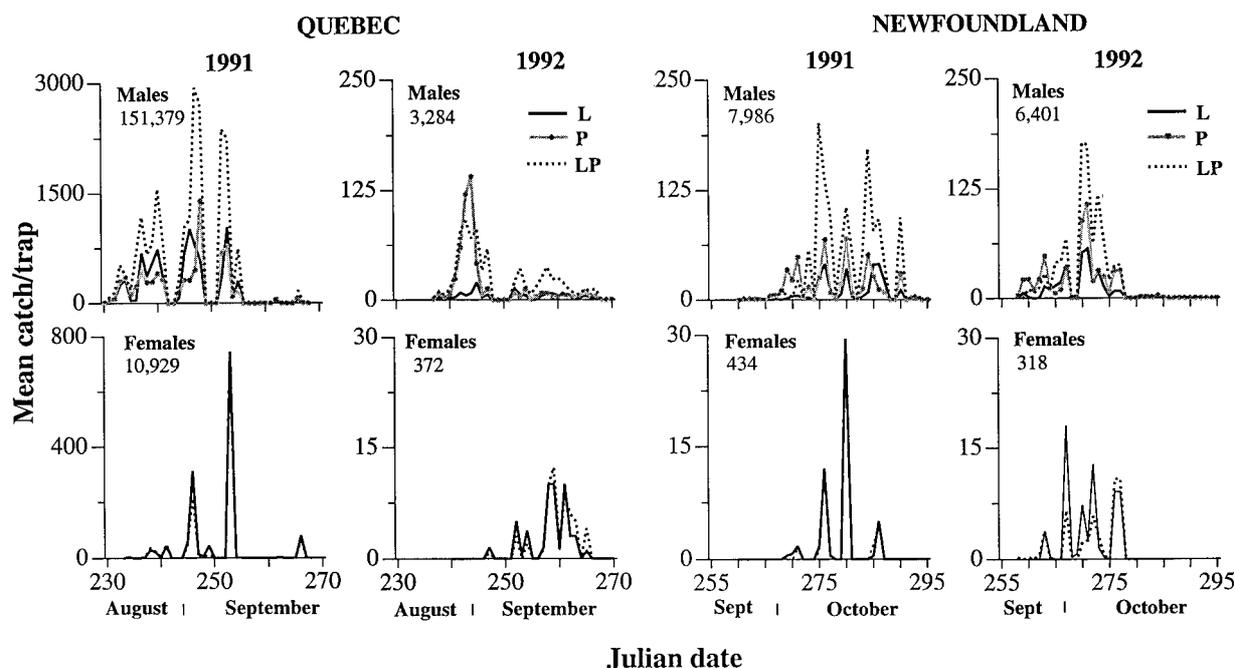


Figure 1. The mean number of eastern hemlock looper, *Lambdina fiscellaria fiscellaria*, male and female adults caught in light (L), pheromone (P) and light + pheromone (LP) traps throughout the 1991 and 1992 flight periods in Quebec and Newfoundland. The total number of males and females caught is indicated in each graph.

in P traps were lower than in L traps following the onset of female flight on day 237. In contrast, after the second peak of female captures on day 246, more males were caught in P than L traps. At the end of the season, when female catches were maximum (day 254), L and P traps again captured similar numbers. Finally, irrespective of the time during the flight season, the number of males caught in LP (54.1%) was always greater than those captured in L (22.0%) and P (19.0%) traps. In the case of females, similar numbers were caught in L (50.2%) and LP (45.0%) traps. Female catches increased over the season and all peaks of activity were well synchronized with those of males. Trap catches of both sexes were considerably reduced at temperatures below 10 °C.

In 1992, the seasonal pattern of male trap catches was quite different, probably associated with the 45-fold decline in the population density from the previous year (Figure 1). While P and LP traps were effective before females were active, L traps attracted very few males. Moreover, once female activity started, the efficacy of all three traps declined drastically and remained low until the end of the flight. As in 1991, the LP traps captured the greatest number of males (56.1%) but in 1992, P traps (31.4%) captured

more than L traps (10.8%). The seasonal flight pattern of females was similar to that observed in 1991 (Figure 1).

In Newfoundland, where population densities were low in both years, male flight activity started later and lasted longer in 1991 than in 1992 (Figure 1), possibly due to cooler environmental conditions associated with the presence of icebergs along the coast of the island during the whole summer. Males were captured more frequently in P than in other traps at the beginning of the flights for both years but the performance of P traps generally declined following the appearance of females. More males were attracted to P than L traps in both 1991 (27 and 14%) and 1992 (29.3 and 17.3%) which is similar to the patterns observed under the 1992 low density conditions in Quebec. LP traps (59 and 53%) had the highest captures in both years. As observed in Quebec, females were captured equally in both L (49.2 and 59.4%) and LP (45.9 and 32%) traps throughout both seasons.

In addition to seasonal differences, the efficacy of the different traps also varied depending on temperatures (Figure 2). In Quebec, the relative increase in P compared with L captures was significant only under cool nights in both years (Temp\*(L vs P) 1991:  $F=8.7$ ,

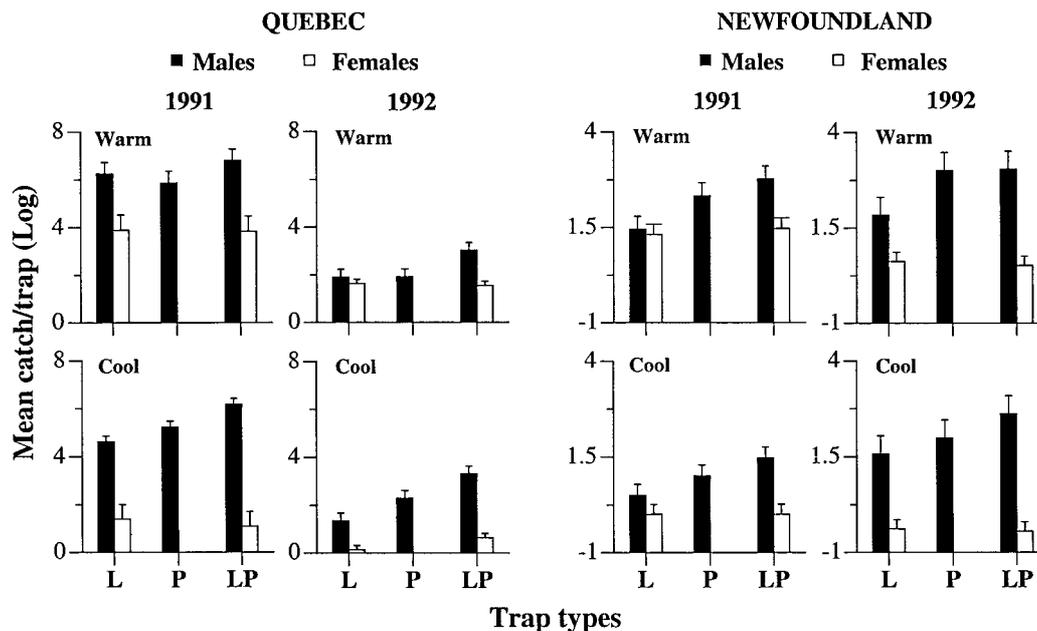


Figure 2. The mean total number (expressed as log) of eastern hemlock looper, *Lambdina fuscicornis fuscicornis*, male and female adults caught in light (L), pheromone (P) and light + pheromone (LP) traps during warm ( $\geq 11^\circ\text{C}$ ) and cool ( $< 11^\circ\text{C}$ ) nights of the 1991 and 1992 flights in Quebec and Newfoundland.

$P < 0.02$ ; 1992:  $F = 7.6$ ,  $P < 0.02$ ), a trend also seen when comparing LP relative to L traps (Temp\*(LP vs L) 1991:  $F = 8.8$ ,  $P < 0.02$ ; 1992:  $F = 6.2$ ,  $P < 0.03$ ). In contrast, the increase in LP relative to P traps was significant in both years (1991:  $F = 17.3$ ,  $P < 0.006$ ; 1992:  $F = 17.2$ ,  $P < 0.003$ ) irrespective of the temperature (Temp\*(LP vs P) 1991: 0.00,  $P = 0.9$ ; 1992: 0.1,  $P = 0.8$ ). In both years, females were equally attracted to L and LP traps regardless of temperature (Temp\*(L vs LP) 1991:  $F = 0.5$ ,  $P = 0.6$ ; 1992:  $F = 0.00$ ,  $P = 0.9$ ).

In Newfoundland, while the effect of temperature on the number of males caught in the different traps was the same for both years, the response differed from the pattern observed in Quebec (Figure 2). For instance, the response to P was significantly higher than to L traps (1991:  $F = 8.2$ ,  $P < 0.01$ ; 1992:  $F = 5.6$ ,  $P < 0.04$ ) as was the response to LP traps (1991:  $F = 22.2$ ,  $P < 0.001$ ; 1992:  $F = 11.3$ ,  $P < 0.008$ ). The responses were consistent irrespective of temperature (Temp\*(L vs P) 1991:  $F = 1.4$ ,  $P = 0.3$ ; 1992:  $F = 1.6$ ,  $P = 0.2$ ) (Temp\*(LP vs L) 1991:  $F = 1.2$ ,  $P = 0.3$ ; 1992:  $F = 0.2$ ,  $P = 0.8$ ). However, differences between P and LP trap catches were not statistically significant (1991:  $F = 3.5$ ,  $P = 0.1$ ; 1992:  $F = 0.9$ ,  $P = 0.4$ ) under either temperature (Temp\*(P vs LP) 1991:  $F = 0.01$ ,  $P = 0.9$ ; 1992:  $F = 1.0$ ,  $P = 0.3$ ) (Figure 4). As seen in Quebec, females were always equally attracted to L and

LP traps (1991:  $F = 0.2$ ,  $P = 0.7$ ; 1992:  $F = 0.2$ ,  $P = 0.7$ ) at both temperatures (Temp\*(L vs LP) 1991:  $F = 0.2$ ,  $P = 0.7$ ; 1992:  $F = 0.02$ ,  $P = 0.9$ ).

In Quebec, the diel periodicity of male captures in the different treatments was significantly influenced by temperature (Figure 3). Males were attracted to L traps early in the night (21:00) at warm temperatures, while maximal attraction to both P and LP traps occurred several hours later (23:00). Under cool conditions, trap catches were lower in all trap types and the peaks occurred at the same time (21:00). Female catches in both L and LP traps were maximum around nightfall (21:00) under warm nights. On cool nights, female captures were practically non-existent, with no activity being detected at temperatures below  $10^\circ\text{C}$  (Figure 3).

Under warm nights in Newfoundland, the hourly patterns of male captures in all traps was similar, with activity increasing from 22:00 to 02:00. In all cases captures declined at 01:00 (Figure 3). As seen in Quebec, light plus pheromone had an additive effect on trap captures. On cool nights, male captures were significantly reduced in all traps, and although males were captured throughout the night there was no evidence of a peak activity period. Under warm temperatures there was no evidence of periodicity of female trap catches although the highest numbers were

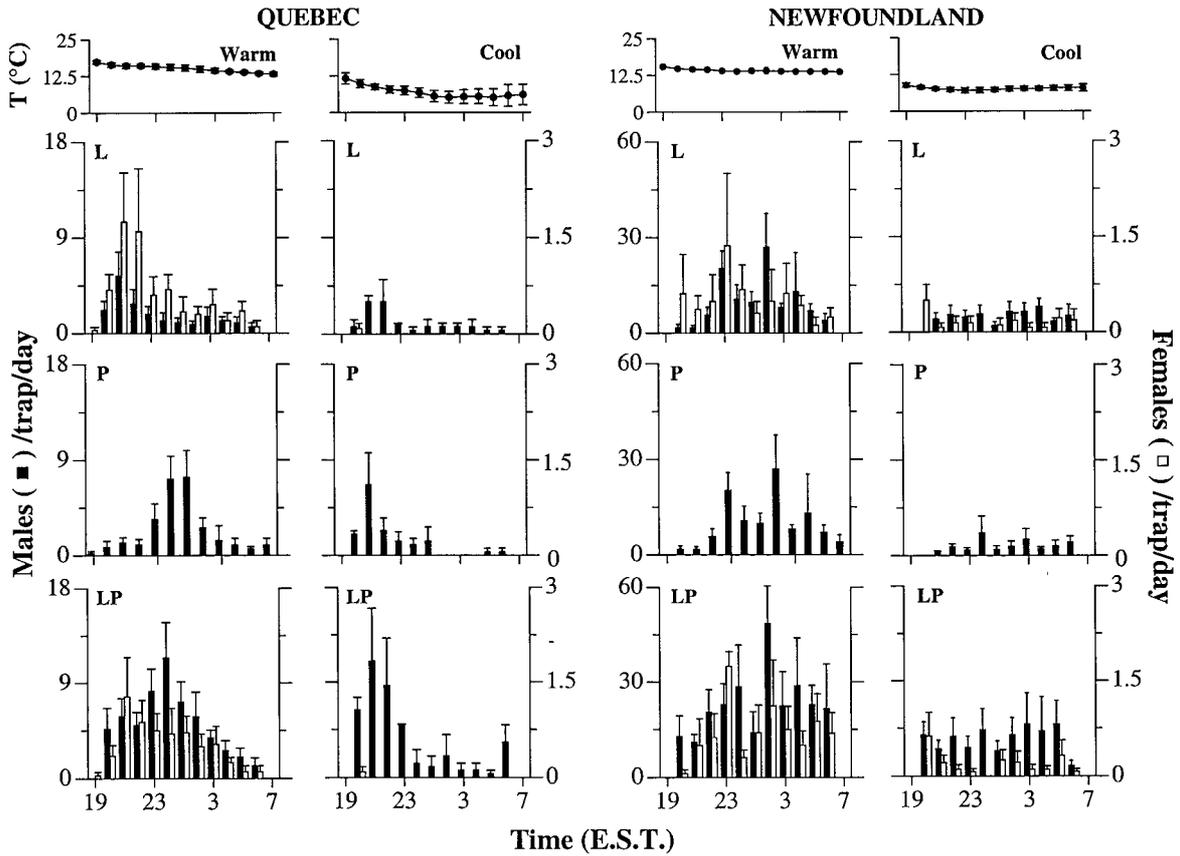


Figure 3. The mean number of eastern hemlock looper, *Lambdina fiscellaria fiscellaria*, male and female adults caught at hourly intervals in light (L), pheromone (P) and light + pheromone (LP) traps during warm ( $\geq 11^\circ\text{C}$ ) and cool nights ( $< 11^\circ\text{C}$ ) of the 1991 and 1992 flights in Quebec and Newfoundland. The upper graphs indicate the mean hourly temperatures during warm and cool nights.

captured in both L and LP traps at 23:00. On cool nights, very few females were captured in L and LP traps, but in both cases the highest numbers occurred at nightfall (Figure 3).

In the Quebec population, there was a significant linear decline in male (1991:  $F=134.6$ ,  $P<0.001$ ; 1992:  $F=66.1$ ,  $P<0.001$ ) and female body mass (1991:  $F=250.9$ ,  $P<0.001$ ; 1992:  $F=19.6$ ,  $P<0.001$ ) over each flight season (Figure 4). However, while the decline in male mass followed the same trend in both years (Year\*time Male:  $F=0.6$ ,  $P=0.5$ ) in females, it was more pronounced in 1991 than in 1992, as reflected by the significant interaction between the two factors (Year\*time Female:  $F=9.6$ ,  $P<0.001$ ). Overall, body mass of both sexes was less in 1992 than 1991 (Male:  $F=146.6$ ,  $P<0.001$ ; Female:  $F=107.2$ ,  $P<0.001$ ), and in both years males were lighter than females (Figure 4). A quite different pattern was seen when the wing surface area was used as an estimate

of body size (Figure 4). Males captured in 1991 were the same size throughout the flight period ( $F=0.00$ ;  $P=0.9$ ), but in 1992, males caught at the end of the season were significantly smaller than those captured at the beginning ( $F=10.5$ ,  $P<0.001$ ). A somewhat different trend was observed in females as body size decreased over the season in 1991 ( $F=4.9$ ,  $P<0.03$ ), but remained constant in 1992 ( $F=0.5$ ,  $P=0.5$ ) (Figure 4).

In Newfoundland, a significant seasonal linear decline was seen in male (1991:  $F=13.6$ ,  $P<0.003$ ; 1992:  $F=20.2$ ,  $P<0.001$ ) and female body mass (1991:  $F=18.4$ ,  $P<0.001$ ; 1992:  $F=30.0$ ,  $P<0.001$ ), with the trend being the same in both years (Year\*time male:  $F=1.1$ ,  $P=0.4$ ; female:  $F=2.6$ ,  $P=0.1$ ) (Figure 4). Overall, males caught in 1992 were heavier than those in 1991 ( $F=191.4$ ,  $P<0.001$ ), while the body mass of females was similar in both years ( $F=0.00$ ,  $P=0.9$ ). In contrast, there was no seasonal linear decline in male (1991:  $F=1.6$ ,  $P=0.1$ ; 1992:

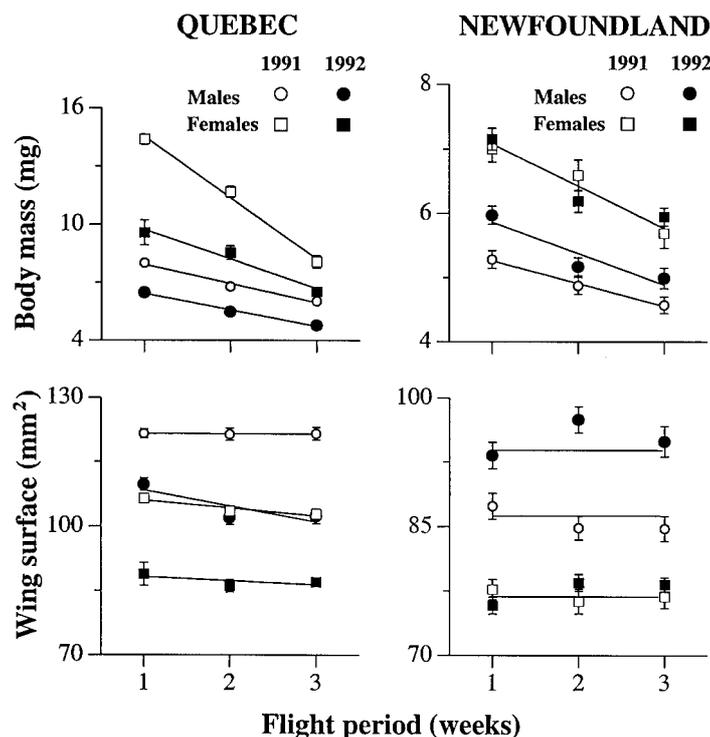


Figure 4. The mean dry body mass and the mean wing surface area of eastern hemlock looper, *Lambdina fiscellaria fiscellaria*, male and female adults caught in light (L), pheromone (P) and light + pheromone (LP) traps at three intervals of one week during the 1991 and 1992 flights in Quebec and Newfoundland.

F=0.5, P=0.5) or female wing surface area (1991: F=0.2, P=0.7; 1992 F=3.4, P=0.1) in either year. Furthermore, overall, males had significantly larger wings in 1992 than in 1991 (F=57.6, P<0.001), while there were no such differences between female populations (F=0.4, P=0.6). Irrespective of the year, females were heavier and had smaller wings than males at both sites (Figure 4).

Females that mated only once were encountered more frequently than virgins or multiply-mated individuals, regardless of trap types, site or year (data not shown). In Quebec in 1991, the number of virgins declined while the number of multiply-mated females increased later in the season. In 1992, very few virgins were captured but as for 1991 the frequency of multiply-mated females increased at the end of the season. The seasonal patterns for 1991 and 1992 in Newfoundland were similar to those observed for the corresponding years in Quebec.

In Quebec, using the wing surface area to dry body mass relationships for laboratory-reared gravid and spent females, the estimated proportion of eggs laid by the females at the time they were captured varied

considerably over the three week periods of sampling (Figure 5). In 1991, females caught during the first week had already laid 50% of their egg complement compared with 56% and 84% during the following 2 weeks, respectively. Similar trends were observed in the lower population density in 1992. Based on the cumulative proportion of eggs laid by the EHL females at 10, 15 and 20 °C, the time required for feral females to lay 50% of the total egg complement (approximately 180 eggs per female at each temperature regime), would vary between 5, 7 and 12 days, respectively (data not shown). This suggests that females had emerged for at least a week before being captured in any trap type.

## Discussion

It has been generally reported that P traps are more efficient than L traps in attracting moths early in the season when populations are low, while the inverse is true later in the flight period, when the density is at its highest level (Hendricks et al., 1973; Starratt & McLeod, 1976; Campbell et al., 1992; Mahrt et

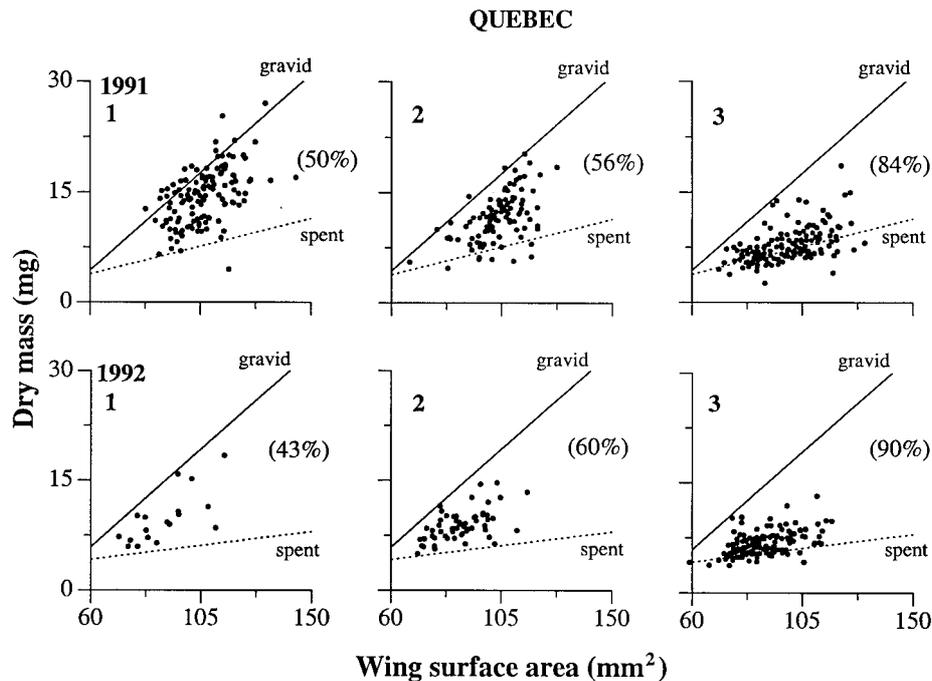


Figure 5. The linear relationship between dry weight and wing surface area of fully gravid (—), spent (---) and feral females (●) of eastern hemlock looper, *Lambdina fiscellaria fiscellaria*, caught in the different traps during three intervals of one week (1, 2, 3) of the 1991 and 1992 flights in Quebec. The estimated proportion of eggs laid by females prior to capture is indicated in parentheses in each graph.

al., 1987; Srivastava & Srivastava, 1989). A similar population density-trap catch relationship was also observed with respect to the total trap catches, with P traps being more efficient at low densities but not at high ones (Roach, 1975; Fletcher-Howell et al., 1983; Herbert et al., 1991). Several studies have suggested that the decline in P traps at higher densities was the result of increased competition by feral females for males (Roach, 1975; Starratt & McLeod, 1976; Oloumi-Sadeghi et al., 1975; Kennedy & Anderson, 1980; Fletcher-Howell et al., 1983; Legg & Chiang, 1984; Campbell et al., 1992) however, very few have provided experimental data to support this hypothesis (Oloumi-Sadeghi et al., 1975; Campbell et al., 1992).

In Quebec, the seasonal changes and the total number of males caught in L and P traps during both flights were generally consistent with the previously described effect of moth density on relative trap efficiency. For instance when densities were high in 1991, P traps were less effective than L traps, even at the beginning of the flight period. Furthermore, soon after the initiation of female flight, P trap catches declined gradually and remained low for several days (days 235–245) at a time when L trap catches increased. Given that the majority of females caught during that

period (days 240–250) were mated and had already laid  $\leq 50\%$  of their eggs in the previous 5 to 12 days, it is reasonable to conclude that the decline in P trap catches around day 235 was the result of competition with calling virgin females. The subsequent increase in P trap catches (days 247–249) would result from lower levels of competition as the majority of females were almost spent at that time (Figure 5).

In 1992 in Quebec, and in both years in Newfoundland, P traps were more efficient than L or LP early in the season, as expected under lower density conditions. This was followed by a slight decline in P captures, probably due to competition with virgins. However, in Quebec, male catches were subsequently quite low in all traps even though temperature was not a limiting factor for male flight. The observed progressive loss in male body mass would normally result in a lower wing loading (Angelo & Slansky, 1984), however in this case there was, as evidenced by the wing surface area measurements, an associated decrease in overall size of males captured. One possible explanation of the overall drop in trap captures may be related to a decline in habitat quality following the high degree of defoliation in 1991 leading to a decline in adult longevity, a rapid loss of vigor and/or a

lower level of response to the different stimuli. The observed decline in male size could also be related to the decline in host plant quality following the defoliation in 1991. Males captured later in the 1992 flight period could be from larvae that fed on previously defoliated trees, resulting in a lower adult weight and a slower rate of development. Similarly, the marked decline in population density in the 1991 Newfoundland site was probably associated with suboptimal ecological conditions, given that males were significantly lighter and smaller than those caught in 1992. However, the drop in moth density was not as abrupt as the one observed in Quebec, which may explain why the level of male activity did not markedly differ between sites.

As expected, given that very few females are ever caught in P traps, female trap catches were similar for L and LP traps in both regions for both years. As observed with males, female flight activity increased towards the end of the season most probably as the result of a decreasing wing loading due to egg deposition. If flight activity is associated with wing loading, this would explain why so few virgins were caught, given that they have greater body mass than males but significantly smaller wing surface areas. Whether mated females were actively searching for oviposition and/or feeding sites when attracted to L traps remains to be determined through visual observations over several nights following emergence. It has been reported that EHL females frequently drag the tip of their abdomen on the substrate, an activity possibly associated with oviposition (West & Bowers, 1994). The incidence of marking was generally more pronounced in mated than virgin females, and the peak of marking coincides with the time we captured females in light traps (Figures 5, 6). This strongly supports the idea that female loopers are flying in search of new oviposition sites.

Several abiotic factors play a significant role in the behavioral responses to both pheromone traps and calling females (for a review see McNeil, 1991). However, the influence of such variables on the performance of different traps operating simultaneously has received little attention (Gentry & Davis, 1973; Dent & Pawar, 1988). In Quebec, temperature significantly influenced the time at which males responded to P and LP traps, with peak activity occurring earlier under cool rather than warm nights, a shift reported for several other moth species (Cardé & Roelofs, 1973; Comeau et al., 1976; Bollinger et al., 1977; Webb & Berisford, 1978; Baker & Cardé, 1979; Turgeon et al., 1983). Similar temperature-related changes have been

reported in the calling behavior of virgin females of several moth species (Baker & Cardé, 1979; Teal & Byers, 1980; Turgeon & McNeil, 1983; Haynes & Birch, 1984; Delisle & McNeil, 1987, a, b; Delisle, 1992) and is true for the EHL (West & Bowers, 1994). Peak activity in L traps always occurred early in the night, so the advance observed in male response to P on cool nights would increase the level of competition between traps. The fact that fewer males were caught in L than P traps under cool nights suggests that the pheromone is a stronger stimulus than light (Figure 2). Under warm nights, there should be less competition between traps, an idea supported by the fact that the patterns of male response to light and pheromone are temporally separated (Figure 3), and thus L and P trap catches did not statistically differ (Figure 2).

In Newfoundland a different behavioral response was observed. Under warm nights, similar temporal patterns of male captures were observed in all traps, with the activity generally being more important in the middle than at the beginning or end of the night. This suggests a strong effect of competition between traps during a significant portion of the scotophase. Furthermore, under cool nights, there was no evidence of a significant advance in the response of males to pheromone, contrary to the pattern observed in Quebec. Two factors may explain these differences. Firstly, temperature at the beginning of the night was already lower than in Quebec, so by the time flight occurred, the temperature had dropped below the threshold for male flight. Secondly, it is possible that the temperature decline was not sufficiently pronounced to elicit a significant shift in the responsiveness of males to pheromone. For example, in the obliquebanded leafroller, *Choristoneura rosaceana*, the advance in the onset of female calling occurred much earlier under a cool thermocycle ( $17^{\circ} - 9^{\circ}\text{C}$ ;  $X = 14.9^{\circ}\text{C}$ ) than at  $15^{\circ}\text{C}$  constant (Delisle, 1992). However, despite these irregular patterns, the overall trap catches obtained in both years clearly demonstrated that male loopers were more responsive to P than L, irrespective of the temperature conditions at night (Figure 2).

Generally, male captures in P traps occurred much later at night in Newfoundland (03:00) than in Quebec (21:00), even though during warm nights, the temperature was similar in both regions (Figure 3). However, given that the flight period started nearly 3 weeks later in Newfoundland than in Quebec, one possible explanation may be the effect of photoperiod modulating differently the responsiveness of males to

pheromone. This is consistent with findings reported for the rice stem borer, *Chilo suppressalis*, where males held under short days responded significantly later in the scotophase than under long days (Kanno, 1981). There may also be geographic differences in the populations. The onset of mating in the western hemlock looper at 20 °C under L12:D12 photoperiod occurred in the second half of the scotophase (Ostaff et al., 1974), while under similar conditions, most matings of the EHL from Quebec occurred during the first half of the night (Delisle, unpublished). Thus, it is possible that there are two geographic strains of the EHL which have adapted to maritime and continental ecological conditions.

Previous studies have suggested that the use of blacklight traps baited with either virgin females (Hoffman et al., 1966; Henneberry & Howland, 1966; Henneberry et al., 1967; Hendricks, 1968) or a synthetic lure (Gentry & Davis, 1973) could lead to effective control of male population, due to the additive effect of both stimuli on trap catches. However, it has been argued that the impact of this approach would also depend on whether baited traps will be in direct competition with the native virgin females (Hoffman et al., 1966). In the present study, despite the additive effect of both stimuli on male trap catches, there was no evidence that such a trapping system was competitive enough to reduce mating activities in the population, given that more than 80% of all females caught were successfully mated. Furthermore, the ability of EHL males to mate consecutively for several nights without any significant negative effect on their reproductive potential (Delisle, unpubl.) raised the question as to whether a reduced male population will have any consequences on the density of the subsequent generation. Similarly, the use of L traps alone or in combination with P to suppress female population will be of little value, given that only a low proportion of unmated females was captured in the light traps. However, the combined use of P and L traps may prove useful should a pheromone mating disruption program be implemented for the EHL. Low male captures in P traps and the absence of mated females later in the season would suggest mating disruption was successful. One could argue that a higher proportion of virgin females caught in L traps early in the season could also indicate a significant reduction in the incidence of mating. However, this seems unlikely in the hemlock looper as virgin females have a low capacity of flight and generally do not oviposit for several days following emergence (Delisle, personal

observation). Furthermore, there is no evidence of decreased wing loading due to a massive resorption of eggs (Delisle, personal observation). Thus, the failure to mate is unlikely to lead to an increased number of virgins initiating flight and subsequent increases in trap capture.

The non-selectivity of the L traps in attracting insects has been generally regarded as a disadvantage compared to P traps, especially at low population densities of the target species. However, it did not require a lot more time to sort out the hemlock loopers in the L than P traps following the decline in the EHL population in Quebec in 1992, or in either year of relatively low population densities in Newfoundland. This was not particularly surprising, as there were very few other moth species active in coniferous stands at this time of the year. Thus, the presence of other species would not pose a problem in hemlock looper monitoring programs. However, this aspect would have to be taken into consideration when evaluating the potential of autonomous light traps for monitoring other species.

Another beneficial aspect of using L traps, as reported in this study, would be to help to correlate seasonal changes in male pheromone trap catches with the occurrence of mated females and thus provide a better biological interpretation of the pheromone monitoring system of this economically important pest. Understanding the relationships between ovipositional history and the prevailing environmental conditions may make it easier to obtain estimates of overwintering egg mortality. Furthermore, it may shed light on the conditions that result in the appearance of intersexes in the subsequent generation (Delisle, unpublished), possibly due to unfavorable conditions associated with diapause induction and/or embryonic development

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## References

- Angelo, M. J. & F. Slansky, Jr. 1984. Body building by insects: trade-offs in resource allocation with particular reference to migratory species. *Florida Entomologist* 67(1): 22–41.
- Baker, T. C. & R. T. Cardé, 1979. Endogenous and exogenous factors affecting periodicities of female calling and male sex pheromone response in *Grapholitha molesta* (Busck). *Journal of Insect Physiology* 25: 943–950.
- Bollinger, J. F., H. H. Shorey & L. K. Gaston, 1977. Effect of several temperature regimes on the development and timing of responsiveness of males of *Trichoplusia ni* to the female sex pheromone. *Environmental Entomology* 6: 311–314.
- Bucher, G. E. & G. K. Bracken, 1979. The bertha armyworm, *Mamestra configurata* (Lepidoptera: Noctuidae). An estimate of light and pheromone trap efficiency based on captures of newly emerged moths. *The Canadian Entomologist* 111: 977–984.
- Campbell, C. D., J. F. Walgenbach & G. G. Kennedy, 1992. Comparison of black light and pheromone traps for monitoring *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) in tomato. *Journal of Agricultural Entomology* 9 (1): 17–24.
- Cardé, R. T. & W. L. Roelofs, 1973. Temperature modification of male sex pheromone response and factors affecting female calling in *Holomelina immaculata* (Lepidoptera: Arctiidae). *The Canadian Entomologist* 105: 1505–1512.
- Comeau, A., R. T. Cardé & W. L. Roelofs, 1976. Relationship of ambient temperatures to diel periodicities of sex attraction in six species of Lepidoptera. *The Canadian Entomologist* 108: 415–418.
- Delisle, J., 1992. Age related changes in the calling behaviour and the attractiveness of obliquebanded leafroller virgin females, *Choristoneura rosaceana*, under different constant and fluctuating temperature conditions. *Entomologia Experimentalis & Applicata* 63: 55–62.
- Delisle, J. & J. N. McNeil, 1987a. Calling behaviour and pheromone titre of the true armyworm, *Pseudaletia unipuncta* (Haw.) (Lepidoptera: Noctuidae) under different temperature and photoperiod conditions. *Journal of Insect Physiology* 33: 315–324.
- Delisle, J. & J. N. McNeil, 1987b. The combined effect of photoperiod and temperature on the calling behaviour of the true armyworm, *Pseudaletia unipuncta*. *Physiological Entomology* 12: 157–164.
- Dent, D. R. & C. S. Pawar, 1988. The influence of moonlight and weather on catches of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in light and pheromone traps. *Bulletin of Entomological Research* 72: 175–192.
- Fletcher-Howell, G., D. N. Ferro & S. Butkewich, 1983. Pheromone and blacklight trap monitoring of adult European corn borer (Lepidoptera: Pyralidae) in western Massachusetts. *Environmental Entomology* 12: 531–534.
- Gentry, C. R. & D. R. Davis, 1973. Weather: influence on catches of adult cabbage loopers in traps baited with BL only or with BL plus synthetic sex pheromone. *Environmental Entomology* 2: 1074–1077.
- Gries, G., J. Li, R. Gries, K. N. Slessor, W. W. Bowers, R. J. West, G. G. S. King, E. W. Underhill & J. H. Borden, 1991. 5, 11 dimethylheptadecane and 2, 5-dimethylheptadecane: sex pheromone components of the geometrid moth, *Lambdina fiscellaria fiscellaria*. *Naturwissenschaften* 78: 315–317.
- Haile, D. G., J. W. Snow & J. L. Goodenough, 1973. Reduced capture of tobacco budworm and corn earworm males in electric grid traps baited simultaneously with virgin females of both species. *Journal of Economic Entomology* 66: 739–740.
- Haynes, K. F. & M. C. Birch, 1984. The periodicity of pheromone release and male responsiveness in the artichoke plume moths, *Platyptilia carduidactyla* (Lepidoptera: Pterophoridae). *Physiological Entomology* 9: 287–295.
- Hendricks, D. E., 1968. Use of virgin female tobacco budworms to increase catch of males in blacklight traps and evidence that trap location and wind influence catch. *Journal of Economic Entomology* 61: 1581–1585.
- Hendricks, D. E., H. M. Graham, R. J. Guerra & C. T. Perez, 1973. Comparison of the numbers of tobacco budworms and bollworms caught in sex pheromone traps vs blacklight traps in lower Rio Grande Valley, Texas. *Environmental Entomology* 2: 911–914.
- Henneberry, T. J. & A. F. Howland, 1966. Response of male cabbage loopers to black-light with or without the presence of the female sex pheromone. *Journal of Economic Entomology* 59: 623–626.
- Henneberry, T. J., A. F. Howland & W. W. Wolf, 1967. Combinations of blacklight and virgin females as attractants to cabbage looper moths. *Journal of Economic Entomology* 60: 152–156.
- Herbert, D. A., Jr., G. W. Zehnder & E. R. Day, 1991. Evaluation of a pest advisory for corn earworm (Lepidoptera: Noctuidae) infestations in soybean. *Journal of Economic Entomology* 84: 515–519.
- Hoffman, J. D., F. R. Lawson & B. Peace, 1966. Attraction of blacklight traps baited with virgin female tobacco hornworm moths. *Journal of Economic Entomology* 59: 809–811.
- Jobin, L. J. & C. Coulombe, 1988. The Multi-Pher<sup>®</sup> insect trap. Forestry Canada-Quebec Region. Sainte-Foy, Que. Information Leaflet LFC 24.
- Jobin, L. J. & C. Coulombe, 1992. The Luminoc<sup>®</sup> insect trap. Forestry Canada-Quebec Region. Sainte-Foy, Que. Information Leaflet LFC 26.
- Kanno, H., 1981. Mating behaviour of the rice stem borer moth, *Chilo suppressalis* Walker (Lepidoptera: Pyralidae). VI. Effects of photoperiod on the diel rhythms of mating behaviours. *Applied Entomology & Zoology* 16: 404–411.
- Kennedy, G. G. & T. E. Anderson, 1980. European corn borer trapping in North Carolina with various sex pheromone component blends. *Journal of Economic Entomology* 73: 642–646.
- Legg, D. E. & H. C. Chiang, 1984. European corn borer (Lepidoptera: Pyralidae) infestations: relating captures in pheromone and black-light traps in southern Minnesota cornfields. *Journal of Economic Entomology* 77: 1445–1448.
- Mahrt, G. G., R. L. Stoltz, C. C. Blickenstaff & T. O. Holtzer, 1987. Comparisons between blacklight and pheromone traps for monitoring the western bean cutworm (Lepidoptera: Noctuidae) in south central Idaho. *Journal of Economic Entomology* 80: 242–247.
- Maltais, J., J. Régnière, C. Cloutier, C. Hébert & D. F. Perry, 1989. Seasonal biology of *Meteorus trachynotus* Vier. (Hymenoptera: Braconidae) and of its overwintering host *Choristoneura rosaceana* (Harr.) (Lepidoptera: Tortricidae). *The Canadian Entomologist* 121: 745–756.
- McNeil, J. N., 1991. Behavioral ecology of pheromone-mediated communication in moths and its importance in the use of pheromone traps. *Annual Review of Entomology* 36: 407–430.
- Muirhead-Thomson, R. C., 1991. Trap Responses of Flying Insects. The influence of trap design on capture efficiency. Academic Press, New York.
- Oloumi-Sadeghi, H., W. B. Showers & G. L. Reed, 1975. European corn borer: lack of synchrony of attraction to sex pheromone and capture in light traps. *Journal of Economic Entomology* 68: 663–667.

- Ostaff, D. P., J. H. Borden & R. F. Shepherd, 1974. Reproductive biology of *Lambdina fiscellaria lugubrosa* (Lepidoptera: Geometridae). The Canadian Entomologist 106: 659–665.
- Otvos, I. S., L. J. Clarke & D. S. Durling, 1979. A history of recorded eastern hemlock looper outbreaks in Newfoundland. Canadian Forestry Service Information Report N-X-179, 46 pp.
- Roach, S. H., 1975. *Heliothis zea* and *H. virescens*: moth activity as measured by blacklight and pheromone traps. Journal of Economic Entomology 68: 17–21.
- SAS Institute 1990, SAS User's Guide: Basics. SAS Institute, Cary, NC.
- Starratt, A. N. & D. G. R. McLeod, 1976. Influence of pheromone trap age on capture of the European corn borer. Environmental Entomology 5: 1008–1010.
- Srivastava, C. P. & R. P. Srivastava, 1989. Comparison of *Heliothis armigera* (Hubner) male moth captures in light and pheromone traps at Udaipur, Rajasthan, India. Insect Science & Applicata 10: 565–568.
- Teal, P. E. A. & J. R. Byers, 1980. Biosystematics of the genus *Euxoa* (Lepidoptera: Noctuidae). XIV. Effect of temperature on female calling behavior and temporal partitioning in three sibling species of the *declarata* group. The Canadian Entomologist 112: 113–117.
- Turgeon, J. J. & J. N. McNeil, 1983. Modifications of the calling behaviour of *Pseudaletia unipuncta* (Lepidoptera: Noctuidae), induced by temperature conditions during pupal and adult development. The Canadian Entomologist 115: 1015–1022.
- Turgeon, J. J., J. N. McNeil & W. L. Roelofs, 1983. Field testing of various parameters for the development of a pheromone-based monitoring system for the armyworm, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae). Environmental Entomology 12: 891–894.
- Webb, J. W. & C. W. Berisford, 1978. Temperature modification of flight and response to pheromones in *Rhyaciona frustrana*. Environmental Entomology 7: 278–280.
- West, R. J. & W. W. Bowers, 1994. Factors affecting calling behavior by *Lambdina fiscellaria fiscellaria* (Lepidoptera: Geometridae), under field conditions. Environmental Entomology 23: 122–129.