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Comparison of the daily cycle of adult behavior of five forest lepidoptera from Western Canada, and their response to pheromone traps

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Knowledge of moth behavior is important in interpreting pheromone trap data because numbers caught are related to moth activity, as well as moth densities. There were distinct differences in the 24 h behavior patterns of the five forest lepidoptera compared in this study: western spruce budworm, *Choristoneura occidentalis* FREEMAN, blackheaded budworm, *Acleris gloverana* (WALSINGHAM), forest tent caterpillar, *Malacosoma disstria* HB., hemlock looper, *Lambdina fiscellaria lugubrosa* (HULST) and false hemlock looper, *Nepytia freemani* MUNROE.

In all species, it was important to distinguish between male and female flight behavior and their response to environmental factors. Activity, not related to pheromone attraction, caused high catches with *L. fiscellaria lugubrosa* and *N. freemani*, while coating of sticky surfaces by wing scales caused a rapid decrease in effectiveness of traps by *C. occidentalis*. Placement of traps in relation to tree and shrub distributions and/or in relation to air flow patterns was demonstrated with *A. gloverana*, and temperatures falling below flight threshold during the evening flight period resulted in fewer *C. occidentalis* caught. Pheromones often were long-distance attractants but, with *L. fiscellaria lugubrosa*, they appeared to have only a close-range sensory function. Outbreak patterns and rates of spread were related to moth behavior of *C. occidentalis*, *M. disstria* and *L. fiscellaria lugubrosa*.

Currently there is considerable interest in the use of pheromones to monitor forest pest populations in Western Canada. Access to insect outbreaks in remote areas is often a major problem, as is timing for sampling of specific developmental stages. Monitoring of pests at low, but rising, population levels with attractant traps can be useful because traps can be placed out well in advance of moth flight and recovered any time thereafter. Usefulness of attractant traps and interpretation of data depend upon a knowledge of adult male behavior in response to, and in the absence of, attractive females. A knowledge of adult behavior is also important to understand dispersal processes and resultant defoliation patterns when outbreaks develop.

This paper describes observations made on the daily cycles of adult behavior of five species of moths at outbreak population levels. Observations were made over a number of years at various locations in British Columbia and Alberta. A description of outbreak characteristics of these species was given by SHEPHERD (1977).

Observations were made of flight and sexual activity of the following five forest lepidoptera: western spruce budworm, *Choristoneura occidentalis* FREEMAN (Tortricidae), western blackheaded budworm, *Acleris gloverana* (WALSINGHAM) (Tortricidae), forest tent caterpillar, *Malacosoma disstria* HB. (Lasiocampidae), hemlock looper, *Lambdina fiscellaria lugubrosa* (HULST) (Geometridae), false hemlock looper, *Nepytia freemani* MUNROE (Geometridae).

Pupae collected in the field were sexed and reared. The females were usually placed in small screen cages in an opening centred in a board 45 x 45 cm, covered on both sides with «Stickem Special®». Checkboards without females were used in conjunction with the female-baited boards. In one case, with *C. occidentalis,* a synthetic attractant was available, making it possible to compare catch patterns between female- and synthetic-baited traps. Boards were supported on posts 1 m high and the sticky surfaces were scraped and «Stickem Special» was re-applied as necessary. Fifteen to 25 boards were placed about 30 m apart along the edge of an infested stand. At regular intervals, counts were made of the number of females assuming a calling posture, as well as the number of males caught. The number of moths observed flying during a 2 or 5 minute period over a designated area of crowns was recorded at each interval. Light intensity, wet- and dry-bulb temperatures, and wind direction and speed were noted at each recording interval, usually over 24 h periods. A night-viewing pocketscope (ITT Electronic Tube Division, Roenke, Virginia, USA) to observe flight after dark was available

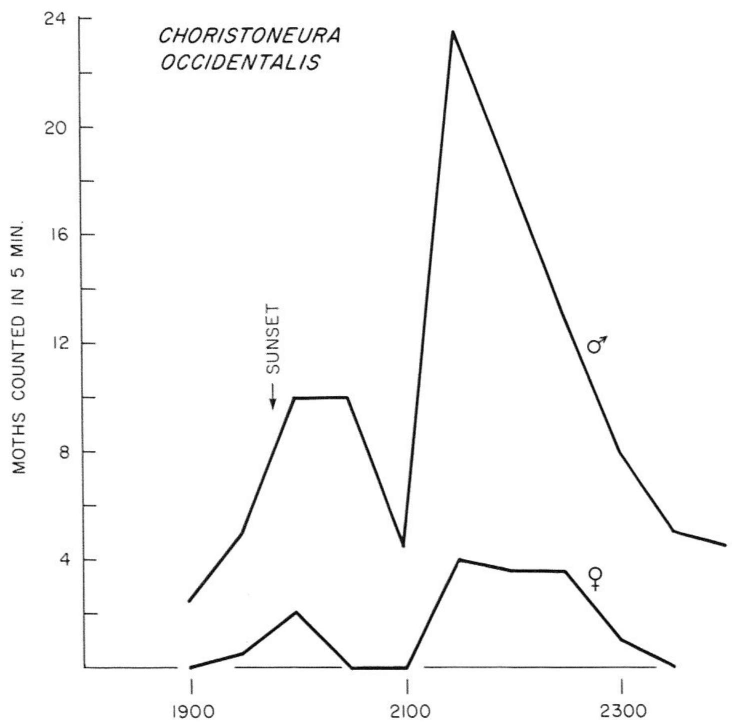

Fig. 1: Counts of male and female spruce budworm moths flying in a designated forest edge; after 22.00 h counts were made with a night-viewing pocketscope.

only for observations of *C. occidentalis.* A test of the efficiency of reusing traps was made with waxed-paper triangular traps 28 x 9.5 cm (LEWIS & MACAULAY, 1976).

RESULTS

Choristoneura occidentalis

The average length of time for calling by *C. occidentalis* was 1½ h and varied from ½ to 3½ h in a sample of 20 females. Calling generally ceased by about 22.00 h Pacific Standard Time, even when temperatures remained above the calling threshold. Under laboratory conditions, SANDERS & LUCUIK (1972) indicated that once calling by the females of *Choristoneura fumiferana* (CLEM.) began, they continued for 7 h until dawn.

Most flight activity observed occurred between 18.20 and 23.30 h, with a maximum for both sexes between 21.30 and 22.30 h, when light intensity had fallen to night time levels below 10 lux. Peaks of activity shortly after dusk are common with many insects (WONG *et al.,* 1971; SANDERS, 1971; ALINIAZEE, 1976) (fig. 1). On two cold evenings, all flight activity ceased by 21.00 h when temperatures fell below 12 °C.

The catching period of males on the sticky boards coincided closely with both the calling period of females and the observed period of flight (fig. 2). Similarly, FATZINGER & ASHER (1971) found that maximum calling behavior of *Dioryctria abietella* (DENIS & SCHIFFERMULLER) coincided with the greatest flight activity, and WICKMAN *et al.* (1975), found that peak flight, trapping and mating activity of *Orgyia pseudotsugata* MCDUNNOUGH all coincided in late afternoon. When synthetic attractant of *C. occidentalis* was used, which gave a continuous release of pheromone, the catch rate of males was almost identical to that of calling females, indicating that male behavior itself may also be a determining factor in the periodicity of activity. Changes in diffusion rates of the synthetic pheromone in response to temperature were probably minimal; during the period of greatest decrease in catches, between 20.30 and 21.00, the temperature drop averaged only about 0.5 °C.

The pink bollworm, *Pectinophora gossypiella* (SAUNDERS), also had a distinct peak in male response when synthetic lure was used (SHARMA *et al.,* 1971), and a comparison of male catches between female-baited and synthetic lure traps of *Diparopsis castanea* HMPS. showed a similar pattern, except proportionately more males were caught by the synthetic lure before and after the peak calling period than by the calling females (MARKS, 1976a). Numbers of trapped males were recorded separately for each side of the board. At one site, with a constant downslope air drainage, 95% of the moths were trapped on the lee side of the boards. At another site near a ridge, with more variable winds, 83% were caught on the predominantly lee side, supporting observations that males moved upwind in response to the attractive scent.

C. occidentalis moths continued to flutter after being trapped in the «Stickem Special», shedding wing and body scales. These scales formed a layer over the surface and decreased the stickiness of the traps. In a test of this effect, triangular traps, used a second night without cleaning, caught an average of 32 moths per trap compared to intermingled, non-used traps, which caught an average of 109

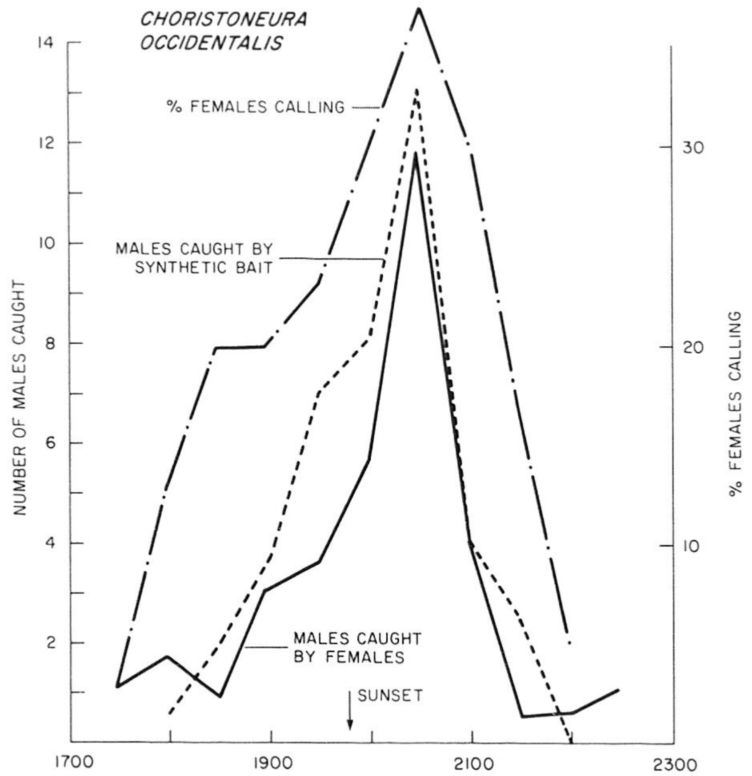

Fig. 2: Percent of western spruce budworm females calling and number of males caught in traps baited with females and with synthetic pheromone.

moths per trap. Even as low as 10 moths trapped the first night were sufficient to decrease trapping efficiency on subsequent nights. It was concluded that the decrease in moth catches was due to the decrease in stickiness, but other factors may have been involved.

Acleris gloverana

A. gloverana adults were small and remained concealed both day and night. Flights were quick and inconspicuous; upon disturbance of the foliage, moths dropped and hid. Almost all moths seen were males, which hid in the brush and lower crowns close to the ground during the day and moved up the tree at dusk and down at dawn.

Flight activity started an hour before sunset (Fig. 3) at 17.30 h, but few moths were caught in the traps until 22.00 h. Presumably, this was when the females began calling, but the moths were too small to detect protruded ovipositors by flashlight. The peak of the catch was at 23.00 h, then numbers decreased gradually until dawn. Adults are longlived; the female *A. gloverana* moths used in this test were 13 days old, and the average age at death of the 18 caged moths was 30 days.

Five pairs of traps were used in an experiment to determine if position of the trap or potency of the female was responsible for the large difference in moth numbers trapped. After two nights of testing with 18 traps, the 5 traps with the lowest numbers of catches, together with their females, were exchanged with the traps catching the highest numbers. In four of the five cases, highest catches on the following night were in the same location as before the exchange. The 18 traps were positioned along a trail across a slope through 1-15 m high, scattered western hemlock trees *(Tsuga heterophylla)*. It was presumed that the differences attributed to position were related to the proximity of trees and shrubs and the variability in the down-slope wind that prevailed during the tests. MARKS (1976b) also found a significant difference in catches of *D. castanea* between locations, as did SWAILES & STRUBLE (1979) with *Scotogramma trifolii* (ROTTENBERG) and *Euxoa auxiliaris* (GROTE).

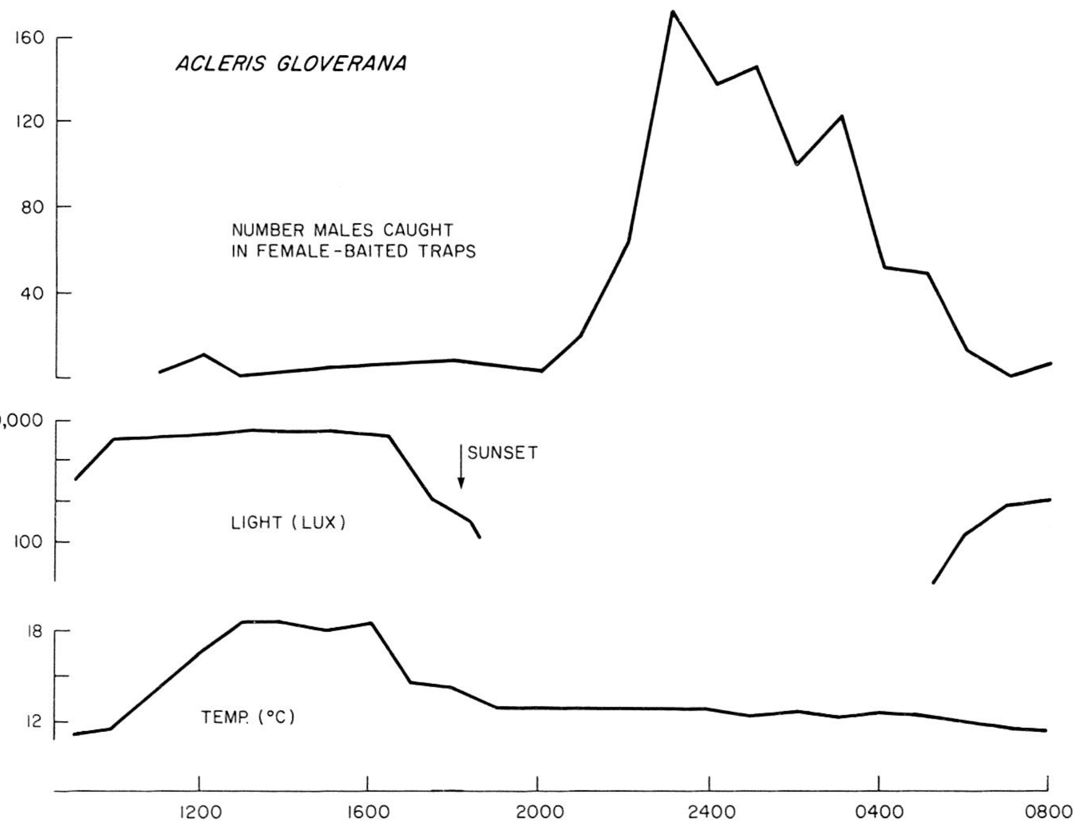

Fig. 3: Number of blackheaded budworm males caught in traps baited with females, in relation to light intensity and temperature.

Malacosoma disstria

Most male moths of *M. disstria* rested between leaves, with occasional short flights through the early part of the day; searching activity over the trees increased at about 15.00 h. Females began emerging from their pupae in late afternoon, swung under the cocoon, expanded their wings, and began calling for males. A rhythmic pumping action was noticeable when the ovipositor was extended, similar to the observations of FATZINGER & ASHER (1971) and PALANISWAMY & SEABROOK (1978). Calling reached a peak just after dark, and resumed at dawn for females which had not mated (Fig. 4). Temperatures as low as 9 °C did not interfere with this behavior. Male flight activity continued into the evening as long as temperatures remained above 11 °C. On one occasion, night temperatures remained above 11 °C and males were caught in traps as late as 23.00 h. The greatest number of males caught in sticky traps occurred when males were flying and females were calling. As these two activities did not coincide completely, the period of overlap was critical for mate location and depended essentially on the length of time temperatures remained above male flight threshold after females started calling. Light rain showers or winds up to 8 kph did not appear to affect male flight activity or female calling behavior.

In the morning, when temperatures were sufficiently high, females could be seen leaving the stand in soaring flights, but even during this relatively quiet

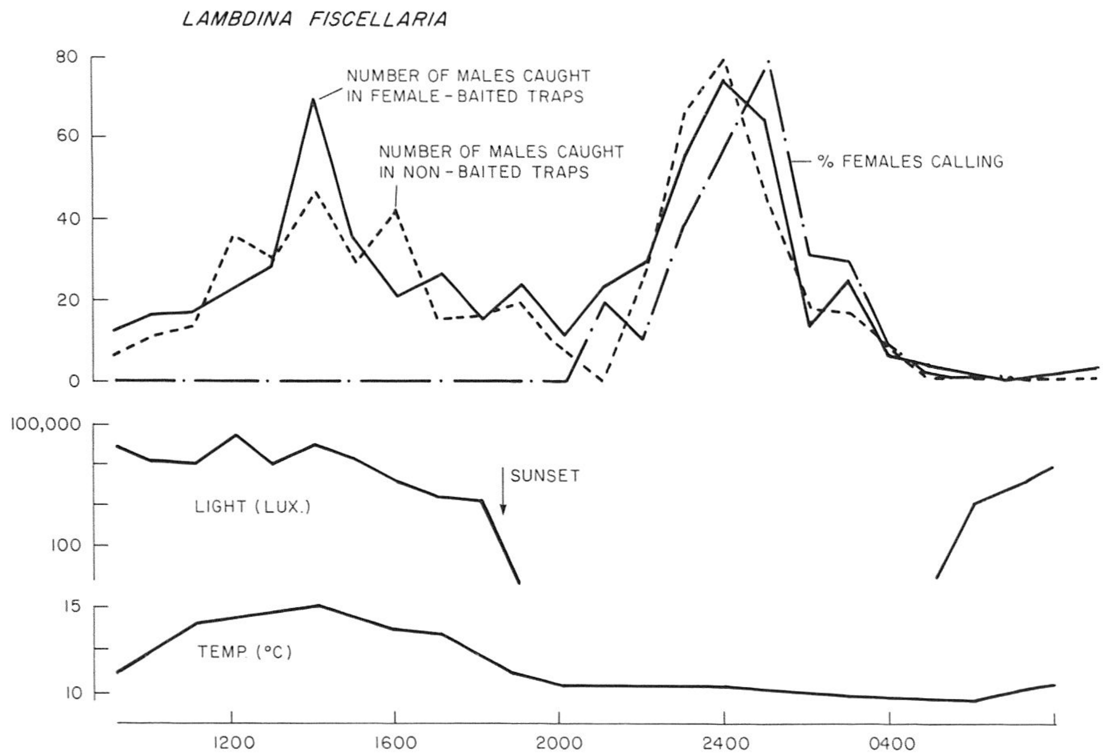

Fig. 4: Percent of forest tent caterpillar females calling and number of males caught in traps baited with females, in relation to light intensity and temperature.

period the numbers flying were predominantly searching males. A study of crop contents of eleven Franklin's Gulls, *Larus pipixcan* WAGLER, preying on moths flying above the stand in late morning, indicated that both males and females were flying in the strata above the trees, the former making up 90% of the 1490 moths consumed. Of the 150 females consumed, 94 had already laid their eggs. The average number of eggs found in the remaining females was 140, which was about average for freshly emerged females collected in a lightly to moderately defoliated stand such as this, indicating these females had not laid any eggs before dispersal.

The effect of age on a female's ability to attract males was tested; 30 females with a range in ages were placed into the traps at 10.00 h and left for 24 h. The average number of males attracted to the traps was 23, 48, 20, 32 and 44 for the 1- to 5-day-old females, respectively, indicating no obvious decline in the female's ability to attract males. This is in contrast to SANDERS & LUCUIK's (1972) test with *C. fumiferana,* where attractiveness decreased after 3 days.

Lambdina fiscellaria lugubrosa

Male *L. fiscellaria lugubrosa* (HULST) could be seen flying throughout the day, often in clusters or bursts of activity, which made relative counts of flying adults of little use. Activity decreased in early morning as temperatures dropped, but there was no distinct photoperiodic response, as with other species (Fig. 5). The peak at 14.00 h was probably related to temperature. Males were continually exploring and landed on all surfaces around the base of trees, looking for females. For this reason, the numbers of males caught in traps with and without females were almost the same and had similar patterns, decreasing to zero at dawn.

Observations indicated that the females emerged from pupae, clustered near the base of the tree, and climbed up the trunk, where searching males found and mated with them. Females in trap cages began calling about 22.00 h and peaked at about 02.00 h.

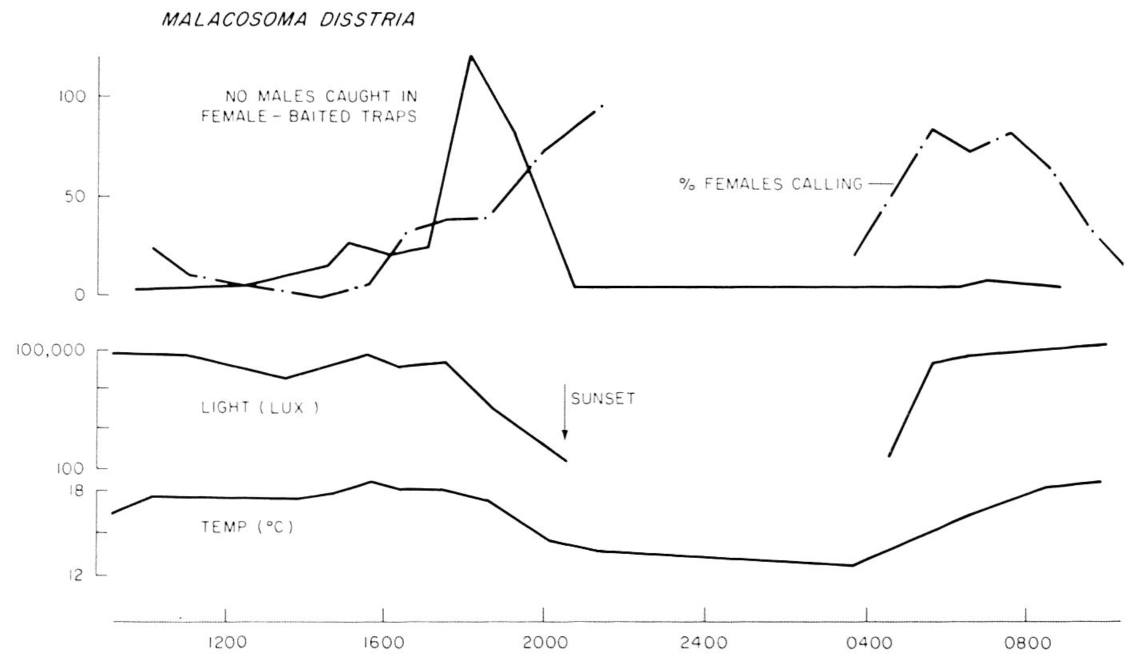

Fig. 5: Percent of hemlock looper females calling and number of males caught in blank traps and traps baited with females, in relation to light intensity and temperature.

Nepytia freemani

Male and female *N. freemani* moths rested around the base of tree trunks and on shrubs during the day. As light decreased at dusk, the moths moved upward into the crowns, where mating took place. Males moved over the foliage searching for females, while the females moved up into the crown; occasionally one soared upward and out of the stand. Activity continued through the night, decreasing at dawn (Fig. 6). As light increased, the moths moved lower in the trees and finally returned to the lower trunks and shrub layer. As with the *L. fiscellaria lugubrosa,* many moths were caught on the traps, even when there was no attraction. The peak at 21.00 and 04.00 h on the non-baited traps was related to the upward and downward movement of the moths through the shrub layer where the traps were located. In this test, not enough females called to determine a reliable pattern, but males caught on traps peaked at 21.00, 01.00 and 04.00 h, the middle period being interpreted as the time of attraction. The calling period of *D. abietella* was similar, beginning 5-6 h and peaking 9 h after it became dark (FATZINGER & ASHER, 1971).

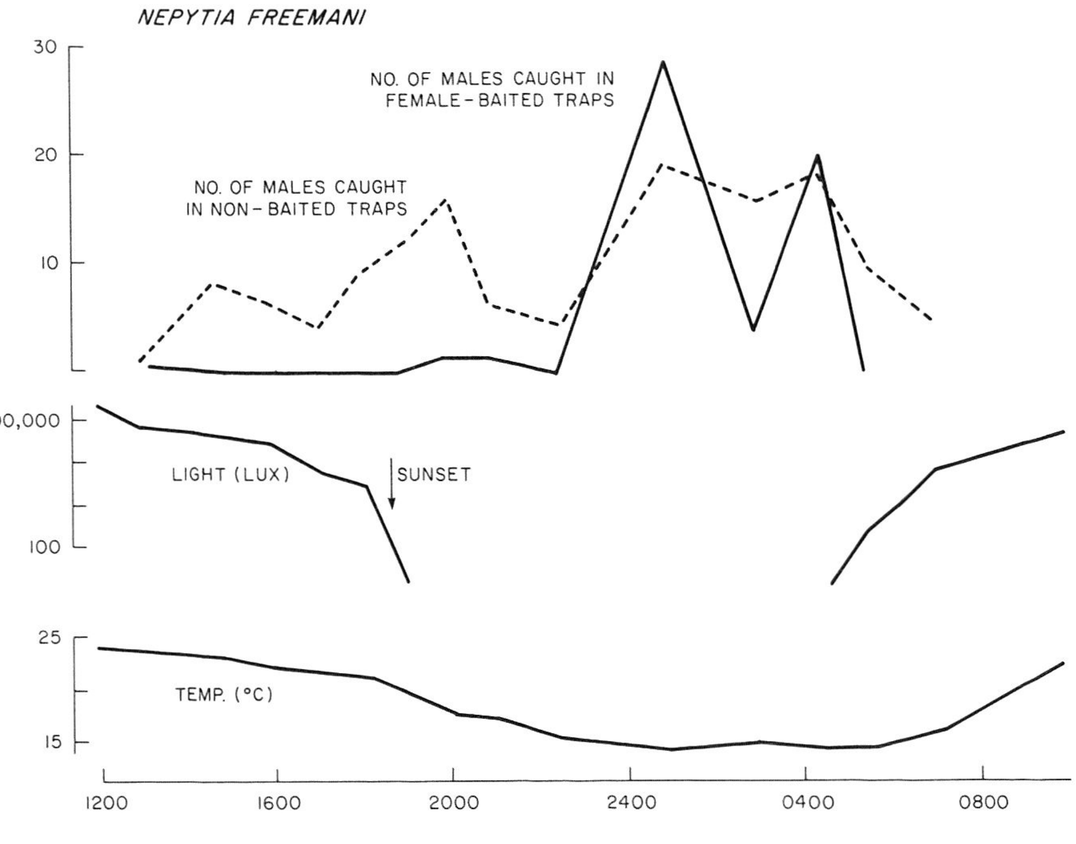

Fig. 6: Number of male false hemlock looper moths caught in blank traps and traps baited with females, in relation to light intensity and temperature.

Comparison among species

The observations of the 5 species of lepidoptera were made at different times of the year and at different latitudes; thus, photoperiods were different for each of the 5 studies. When the catch of males, in response to calling females of each species, was plotted with the time of sunset coincident (Fig. 7), it became evident that peak activity of *M. disstria* occurred before sunset and *C. occidentalis* just after sunset, with the activities of the other three species peaking between 5 and 8 h after sunset. These comparisons assume that moths were reacting to decreasing light intensity near sunset.

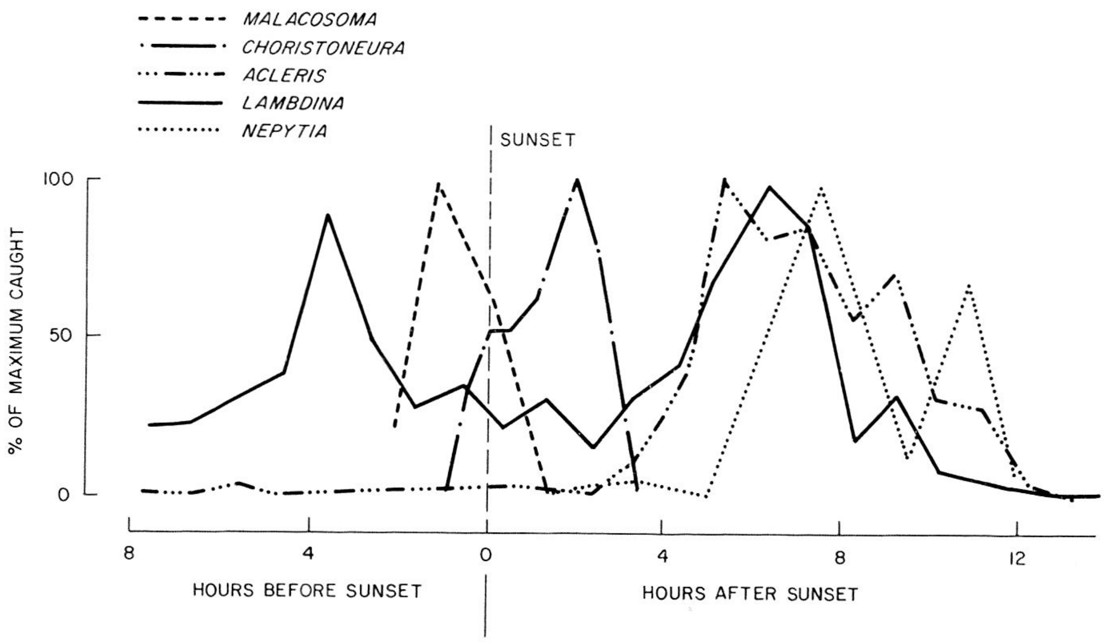

Fig. 7: Number of male moths of 5 species caught in traps baited with females plotted in relation to the number of hours before and after sunset.

Shorey & Gaston (1965) compared four species of moths on a 12.12 light/dark cycle and found that in two species, male response was early in the dark period, one species responded in the middle of the dark period and the remaining species responded toward the end.

Sanders & Lucuik (1972) found in experiments of *C. fumiferana,* under constant temperature and humidity conditions and a range of light/dark cycles, that calling behavior was governed by the time the lights were turned on in the morning. Similarly, Sower, Shorey & Gaston (1971) found that cabbage looper moths, *Trichoplusia ni* (Hübner), followed an endogenous circadian rhythm of female pheromone release which was controlled essentially by the time lights were turned on; however, cool night temperatures modified this by advancing the time of pheromone release up to 3 h. When the male response curves in Fig. 7 were plotted with the times of sunrise coincident (Fig. 8),

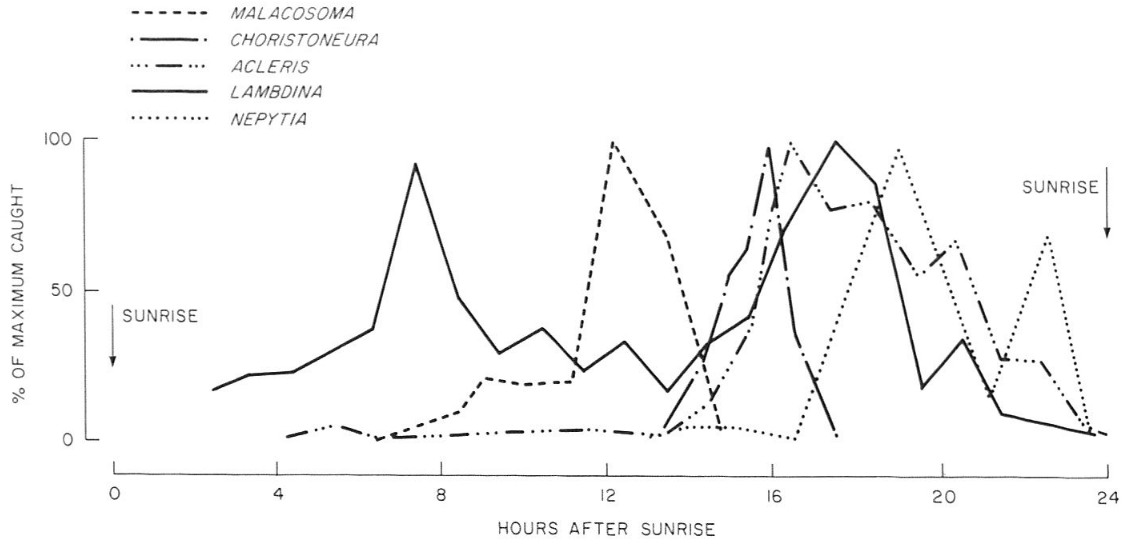

Fig. 8: Number of male moths of 5 species caught in traps baited with females plotted in relation to the number of hours after sunrise.

M. disstria male activity peaked 12 h after sunrise and the others, including *C. occidentalis,* peaked together 16 to 19 h after sunrise.

DISCUSSION

There was a high degree of variability of moth catches in the pheromone traps for various reasons. A specific test indicated that wing scales coming from spruce budworm moths trapped on the first night covered the sticky surface and reduced trap efficiency on subsequent nights. Test boards, therefore, were checked daily and «Stickem Special» was re-applied as necessary. Detection survey traps are often left out for a number of weeks before being checked and this could lead to sampling bias. A covering of scales over the sticky surface of the trap during the first night reduced trap efficiency on subsequent nights. This could also lead to other trapping artifacts. It would be expected, for example, that traps placed out when a high density of moths was present, would catch a high number of moths on the first night, but if traps were placed out a few days before flight began, the few moths caught at the beginning of the flight would reduce trap catches on subsequent nights. The scale problem varied with species; for example, observations in other studies have indicated that wings of *O. pseudosugata* were quickly immobilized in the «Stickem Special» and fewer scales were spread over the surface.

The relative importance of pheromones as long-distance attractants varies among species. Male and female *L. fiscellaria lugubrosa* moths collect on the lower trunks of the trees and the pheromone seems to function as a close sensory mechanism for indicating the readiness of the female to mate, or for excitation of the male. With other species, such as *A. gloverana* and *C. occidentalis,* however, the pheromone motivates the males to seek out the females from a considerable distance.

Relating trap catches to absolute insect densities or comparing catches among locations is often difficult because catches may be related to rate of moth activity rather than density and the former can be directly affected by temperature and other environmental factors. Placement of traps can be important, those upwind of infested stands being expected to collect the highest densities. Nocturnal wind patterns and location of temperature inversions are some of the factors involved in affecting trap catch variability.

Moths obviously utilise pheromones for mate location but may not be totally dependent upon this chemical system. Visual contacts may also be important, and if the chemical senses fail, still allow sufficient matings to carry on the population. A series of amputation experiments of the house fly showed that elimination of any one stimulus system did not significantly reduce mating success (Colwell & Shorey, 1976). The probability of visual searches being successful would be expected to depend upon the time of day when females are receptive. In disruptive trials where chemical searching of the male is inhibited, a conspicuous insect, such as the gypsy moth, *Lymantria dispar* (L.), which begins calling and mating during daylight (Richerson & Cameron, 1974; Odell, 1978), would be expected to obtain a higher proportion of successful matings than *A. gloverana,* which calls and mates in the darkest hours and females remain hidden at all times.

Knowledge of the photoperiod and temperature effects on moths behavior allows one to better predict the time of dispersal. Associating this with air flow analysis allows calculations of the direction and distance moths would be expected to move. For instance, *C. occidentalis* females fly between 18.30 and 22.00 h just after the sun has left the slopes and cool drainage winds have begun to flow. As long as temperatures remain above 12 °C, moths continue to fly and drift down the slopes into main valleys. *M. disstria* moths, however, fly in daytime until late afternoon, when convective heating is still in progress and upslope winds are still functioning. As such, they are more susceptible to long-distance transport by thunderstorms or active cold fronts (Brown, 1965).

Observations of dispersal behavior are useful for understanding outbreak patterns and in designing control strategies. Female *L. fiscellaria lugubrosa* do not appear to leave the stands on dispersal flights, but lay eggs in moss and lichen on tree trunks and around the base of trees; in addition, no wind dispersal of larvae has been observed. Defoliation occurs in distinct patches and shows little evidence of spread after the initial year (Shepherd, 1977). In contrast, female *C. occidentalis* readily undertake dispersal flights and larvae often disperse on silk threads. Outbreaks of this species spread rapidly, defoliation increasing gradually from stand edges to the centre.

Moths of *M. disstria* are strong flyers and spread rapidly from stand to stand, but larvae tend to remain in clusters near the oviposition sites. Outbreak patterns have similarities to both the previous examples; distinct patches of defoliation are noticeable the first year, with a filling in during subsequent years but always retaining a great variability. Defoliation spreads rapidly over large areas when suitable forests are present.

These three case studies indicate that moths are responsible for long-distance dispersal, spreading the population from stand to stand. Larval dispersal is mainly short distance (Mitchell, 1979), tending to smooth out local variability through dispersal within the stands.

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