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Development of a Pheromone-Based Monitoring System for Western Hemlock Looper (Lepidoptera: Geometridae): Effect of Pheromone Dose, Lure Age, and Trap Type

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ABSTRACT A two-component pheromone blend containing a 1:1 (vol:vol) ratio of isomeric 5,11-dimethylheptadecane and isomeric 2,5-dimethylheptadecane was tested in high-capacity Unitraps to monitor populations of the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst), throughout the coastal western hemlock and interior cedar hemlock biogeoclimatic zones of British Columbia. Rubber septa were loaded with each component at doses of 10, 100, 1,000, and 10,000 μg (1992) and 1 and 10 μg (1993). Males demonstrated a dose-dependent response, except that captures in traps with the 2 highest doses (1,000 and 10,000 μg) did not differ. Unitraps with 10-μg lures captured significantly more males than similarly baited sticky traps at the beginning of the flight and with 1- and 10-μg-baited lures at midflight. Both 1- and 10-μg lures maintained their attractiveness over the 3-mo flight season, which extends from mid-August through October, but catches in traps with 1-μg lures were low. In all cases, >80% of the males were captured by the beginning of October. Seasonal trends in trap catches were not closely related to temperature. This research suggests that traps baited with 10-μg lures could be used to monitor populations and detect incipient outbreaks of the western hemlock looper.

KEY WORDS *Lambdina fiscellaria lugubrosa*, monitor, phermone based

THE WESTERN HEMLOCK looper, *Lambdina fiscellaria lugubrosa* (Hulst), is an important defoliator of conifers in British Columbia. Populations increase suddenly, and outbreaks may persist for several years (Harris et al. 1982), during which severe defoliation and extensive tree mortality can occur (Erickson 1984).

Western hemlock looper eggs are laid in September and October (Erickson 1984), on substrates such as moss and lichen and in bark crevices on the trunk and branches of trees (Shore 1989). Hatching occurs in the spring, and there are 4 instars (Erickson 1984). Pupation occurs in crevices in the bark, in moss or lichen, and generally lasts between 10–14 d (Furniss and Carolin 1977, Erickson 1984). Adults fly and mate from late August to mid-October (Erickson 1984). There is 1 generation annually (Furniss and Carolin 1977).

Damage caused by the western hemlock looper, as well as estimated population numbers, are monitored annually in British Columbia by the Forest Insect and Disease Survey (FIDS) of the Canadian Forest Service at a network of sampling sites throughout the province (Harris et al. 1982). Detection and survey methods, including samples of eggs (Kinghorn 1952, Thomson 1958, Carolin et al. 1964), larvae (Harris et al. 1982), and pupae (Shore 1989), often fail to predict forthcoming outbreaks.

The use of pheromones in monitoring and controlling insect populations has become an important tool for pest managers. The presence of a sex pheromone emitted by adult female western hemlock loopers was demonstrated by Ostaff et al. (1974a, b) who observed calling behavior of the female moths and captured males in traps baited with virgin females. Gries et al. (1993) identified the pheromone as a blend of 3 methylated hydrocarbons: 5,11-dimethylheptadecane, 2,5-dimethylheptadecane, and 7-methylheptadecane. Strong attraction of males to pheromone-baited traps in the field (Gries et al. 1993) suggested that a pheromone-based monitoring system could be developed to detect the presence and forecast outbreaks of the western hemlock looper. The western hemlock looper pheromone differs from the 2-component blend (5,11-dimethylheptadecane and 2,5-dimethylheptadecane) of *L. fiscellaria fiscellaria* (Guenée) (Gries et al. 1991). Because the binary blend is strongly attractive to male western hemlock loopers, this blend was chosen to develop as a monitoring tool so that production of commercial lures for eastern and western North America could be synchronized.

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Factors that influence the ability of pheromone-baited traps to monitor populations of a given species include the following: (1) dose, ratio, and release rate of the pheromone blend from the lure (Sanders 1981, 1992; McLaughlin and Heath 1989, Jansson et al. 1990, 1992); (2) effectiveness of the blend at a variety of population densities (Sanders 1992); (3) species specificity of the pheromone blend (Pivnick et al. 1988, McLaughlin and Heath 1989), (4) lure type (Sanders and Meighen 1987); (5) longevity of the lure over the trapping period (Ramaswamy and Cardé 1982, Jansson et al. 1990, Sanders 1992); (6) trap type (Lewis and MacCaulay 1976, Houseweart et al. 1981, Ramaswamy and Cardé 1982, Angerilli and McLean 1984, Sanders 1986, Jansson et al. 1992, Polavarapu and Seabrook 1992, Sanders 1992); (7) trap position (Lewis and MacCaulay 1976, Howell et al. 1990, Sanders 1992); (8) trap density (Houseweart et al. 1981); (9) repellency of killing agents or dead insects within the trap (Sanders 1986); (10) effect of weather on trap catch (Sanders 1981, Knight and Croft 1987, Pitcairn et al. 1990); and (11) ease of management and cost of monitoring (Sanders 1992).

In this study we examined pheromone dose, trap type, and lure longevity in the development of a monitoring system for the western hemlock looper.

Materials and Methods

General Procedures. In July 1992 we established 27 study sites (Evenden 1994, Evenden et al. 1995), in the coastal western hemlock and interior cedar hemlock biogeoclimatic zones (Meidinger and Pojar 1991), throughout southern British Columbia. Selected sites had low, medium, or high infestation levels, based on 1991 FIDS data and consultation with FIDS Rangers. In June 1993, 8 additional sites were established, and 1 site was abandoned because of excessive vandalism in 1992. Sites were grouped geographically into 4 study areas: Revelstoke (Columbia River drainage) (9 sites, 1992; 1993); Clearwater (Thompson River drainage) (7 sites, 1992; 1993); Horsefly (south side of Horsefly Lake) (3 sites, 1992; 6 sites, 1993); and Vancouver (Fraser Valley/Lower Mainland) (8 sites, 1992; 7 sites, 1993). In 1993, Prince George (Robson Valley near McBride to Prince George) (5 sites) was added as a study area.

We obtained mean daily temperatures at 1300 hours from British Columbia Forest Service weather stations in close proximity to study sites.

Components of the pheromone blend, comprising a 1:1 (vol:vol) ratio of isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane, were synthesized by J. Li (Department of Chemistry, Simon Fraser University). Hexane dilutions of the compounds were loaded into rubber septa (S-5509, Lot 72H3489, Sigma, St. Louis, MO) at doses of 10, 100, 1,000, and 10,000 μg of each component in 1992, and 1 and 10 μg in 1993. Septa were mounted on plastic lure holders that were placed in the lid of high-volume, nonsticky Unitraps (Pherotech, Delta, BC). Lures of each dose were kept separated in glass jars or double-bagged Ziploc freezer bags (Dow Chemical, Paris, ON) and were held at 0°C until they were transported in refrigerated containers to study sites.

Before use, traps were washed in soapy water, soaked in hexane, rinsed, and allowed to dry in the sun. Traps were baited on site (29 July–2 August 1992; 7–11 August 1993), with lures remaining in the same traps for the duration of the flight season.

Seasonal Flight Trend and Dose–Response Experiment. At each site, we suspended 1 trap with each of the 10-, 100-, 1,000-, and 10,000-μg (1992) or 1- and 10-μg (1993) lures plus 1 unbaited trap from trees in random order, 1–2 m above the ground at ≥100 m apart. One cube, ≈1 cm^3, of solid-formulated dichlorovos (Green Cross, Mississauga, ON) was placed in each trap to kill captured males. This was later replaced by 2 cubes at each subsequent moth collection. In both 1992 and 1993, male moths were collected 5 times at 2–3 wk intervals from mid-August to the end of October. Moths were stored in plastic bags at 0°C until they were counted.

Lure–Longevity Experiment. We conducted a lure–longevity experiment at 7 sites in the Revelstoke study area from 25 August to 22 October, 1993. At each site, we baited 2 of 5 Unitraps, spaced ≥100 m apart, with either 1-μg or 10-μg lures, while a 5th trap remained unbaited. At 2–3 wk intervals, one 1-μg and one 10-μg lure were each replaced with a freshly loaded lure, whereas the other traps remained with the same lures throughout the flight season. Moths were collected, stored, and counted as above.

Trap-Efficacy Experiment. We conducted a capture-efficacy test of Unitraps and sticky traps in a 1993 experiment at all study sites (7–25 August). Sticky traps consisted of 2-liter milk cartons shaped into open-ended, 3-sided, triangular traps that were wire-suspended with their long axis parallel to the ground. The inner trap area, coated with sticky Bird Tanglefoot (Tanglefoot, Grand Rapids, MI), comprised 825 cm^2. At each study site in Vancouver (7), Clearwater (7), Horsefly (6), Prince George (5) and Revelstoke (9), we baited each of 3 sticky and 3 Unitraps with a 1- or 10-μg lure or left the traps unbaited. We terminated the exper-

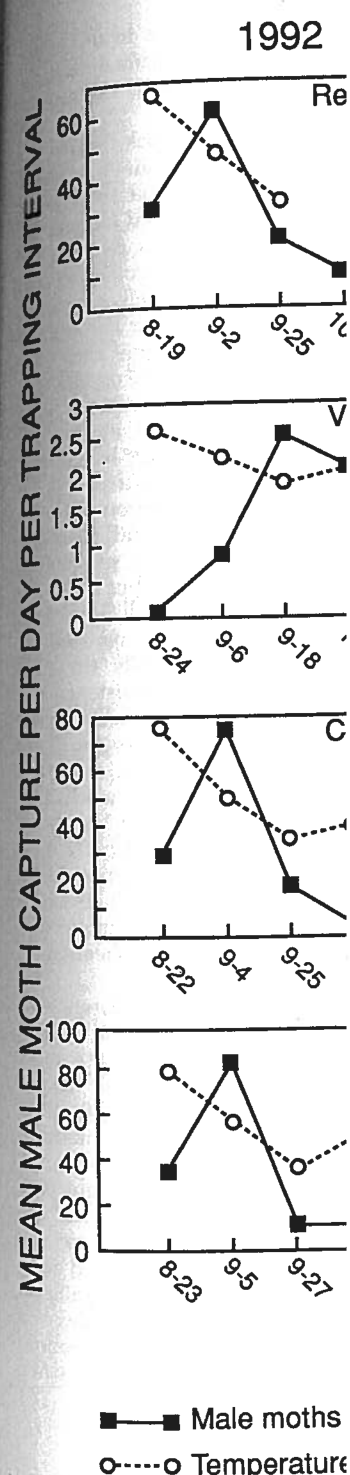

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Fig. 1. Mean numbers of male western hemlock loopers captured per day in 10-μg baited traps and mean daily regional temperatures for each trapping interval throughout the 1992 and 1993 flight seasons. Traps set up 29 July to 2 August 1992 and 7–11 August 1993.

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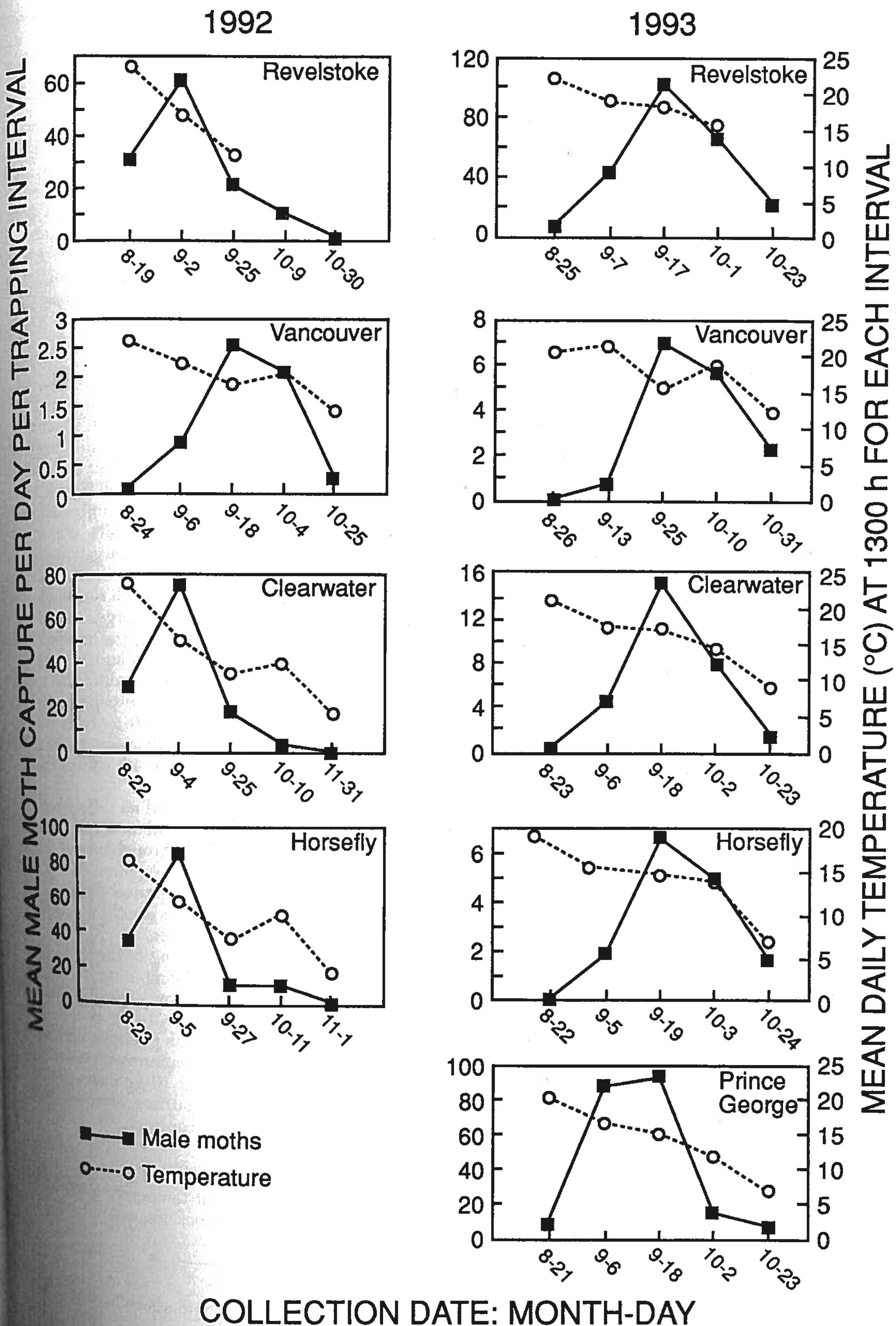
ɔd per day in 10-μg baited traps and mean daily 92 and 1993 flight seasons. Traps set up 29 July



iment after the 1st collection (21–25 August 1993) and transported sticky traps to the laboratory for counting of captured moths. In a 2nd midflight-season experiment (17 September–1 October, 1993) at 7 sites in the Revelstoke area, we baited each of 3 sticky traps and 3 Unitraps with either 1-μg or 10-μg lures or left the traps unbaited.

Statistical Analyses. In all statistical analyses, $\alpha = 0.05$. Moth catches in the dose experiments were transformed by loge(x + 1) to ensure equal variances (Zar 1984) and were then subjected to analysis of variance (ANOVA), followed by Bonferroni t-tests (Dunn 1961) to compare means (SAS Institute 1988). The double split-plot, randomized, complete block design (Winer et al. 1991) resulted in a significant 3-way interaction among geographic area, time of collection, and dose of pheromone ($F = 3.11$, df= 48, 347, $P < 0.0001$). Therefore, analyses for moth catches were divided into each of the 4 (1992) or 5 (1993) study areas for each of the 5 trapping intervals.

To determine differences in the numbers of males captured over time in Unitraps baited with the newly loaded or aged 1- or 10-μg lures, moth captures were compared by a Wilcoxon signed rank test (Wilcoxon 1945, SAS Institute 1988) because of nonnormal distribution of moth catches (Zar 1984).

Moth captures in sticky traps and Unitraps were compared by a Wilcoxon signed rank test (Wilcoxon 1945, SAS Institute 1988) because of nonnormal distributions of moth catches (Zar 1984). In the 2nd part of the trap comparison experiment, which we conducted from 17 September to 1 October, we compared catches in sticky traps with those in freshly baited Unitraps in the lure potency experiment to ensure that the potency of the baits was equal.

Results

Seasonal Flight Trends. Unitraps baited with various doses of the 2 component blend were attractive to male western hemlock loopers throughout the flight period. Onset, peak, and termination of moth capture in 10-μg baited traps (Fig. 1) varied among regions and between years. The flight pattern did not track the temperature, but peak flight in all instances was preceded by temperatures in the 20–25°C range. In all regions and in both years, the temperature line crossed the flight activity curve, indicating a noncorresponding decrease of flight activity and temperature (Fig. 1). The cumulative percentage of total male moth catch throughout the flight season in each area further emphasizes the variation in emergence times and peak flight among areas and between years (Fig. 2). Cumulative trap capture in the various areas indicates that if traps are maintained in the field until the beginning of October, ≈80% of the flight will be sampled (Fig. 2).

Dosage. Male western hemlock loopers responded in a dose-dependent manner to pheromone-baited traps in both 1992 and 1993 (Tables 1 and 2). In 1992, pheromone-baited traps attracted substantiallly more male moths than the unbaited traps in all regions and all collection periods, with the exception of the Horsefly area at collection 1. Data are not reported for the Horsefly area at collection 4 because there were many missing observations. In 1992, captures of males increased with pheromone dose, but response to the 2 highest doses (1,000 and 10,000 μg) was the same (Table 1). In 1993, the 10-μg baited traps attracted significantly more moths than the unbaited control traps, with the exception of the 1st collection period in the Horsefly and Vancouver areas. The 1-μg-baited traps caught substantially more moths than control traps in all but the Prince George or Horsefly areas, where at all 5 and 3 out of 5 collection periods, respectively, unbaited and 1-μg baited traps caught statistically the same number of males (Table 2). The consistency with which the 10-μg dose attracted significantly more moths than the 1-μg dose varied with region (Table 2). In Revelstoke and Prince George, the 10-μg baited traps caught consistently more moths than the 1-μg baited traps. In Horsefly and Vancouver, the 10-μg baited traps caught significantly more moths at all collections with the exception of the first collection. By contrast, the 10-μg baited traps in Clearwater caught significantly more moths than the 1-μg baited traps only at the 4th collection period (Table 2).

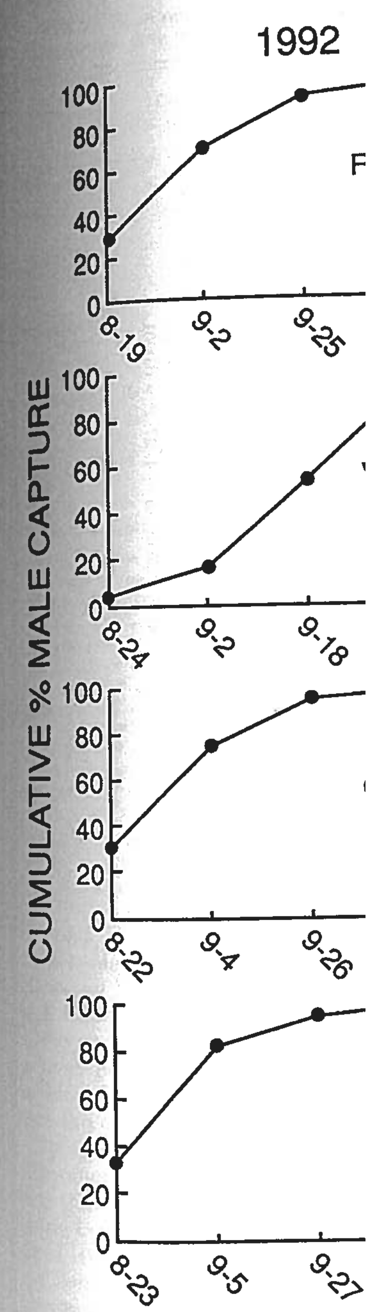
Lure Longevity. We observed no difference between freshly baited lures and original lures at both the 1- and 10-μg doses throughout the entire 3-mo flight season, with the exception of the 10-μg dose at the 4th collection period (Table 3). In the latter case the original lures caught significantly more moths than the new lures.

Trap Type. At the beginning of the flight period, when few moths were flying, a significant difference in trap capture between sticky traps and Unitraps was observed in the 10-μg baited traps (Table 4). At the 4th collection period, a significant influence of trap type on captures of males was observed both at the 1- and 10-μg doses. Saturation of the 825-cm² sticky surface occurred when as few as 100 moths were captured.

Discussion

Although mean ambient temperature and flight patterns of western hemlock loopers did not cor- →

Fig. 2. Cumulative captures of male western hemlock loopers in 10-μg baited traps throughout the flight season 1992 and 1993. Traps set up 29 July to 2 August 1992 and 7–11 August 1993.



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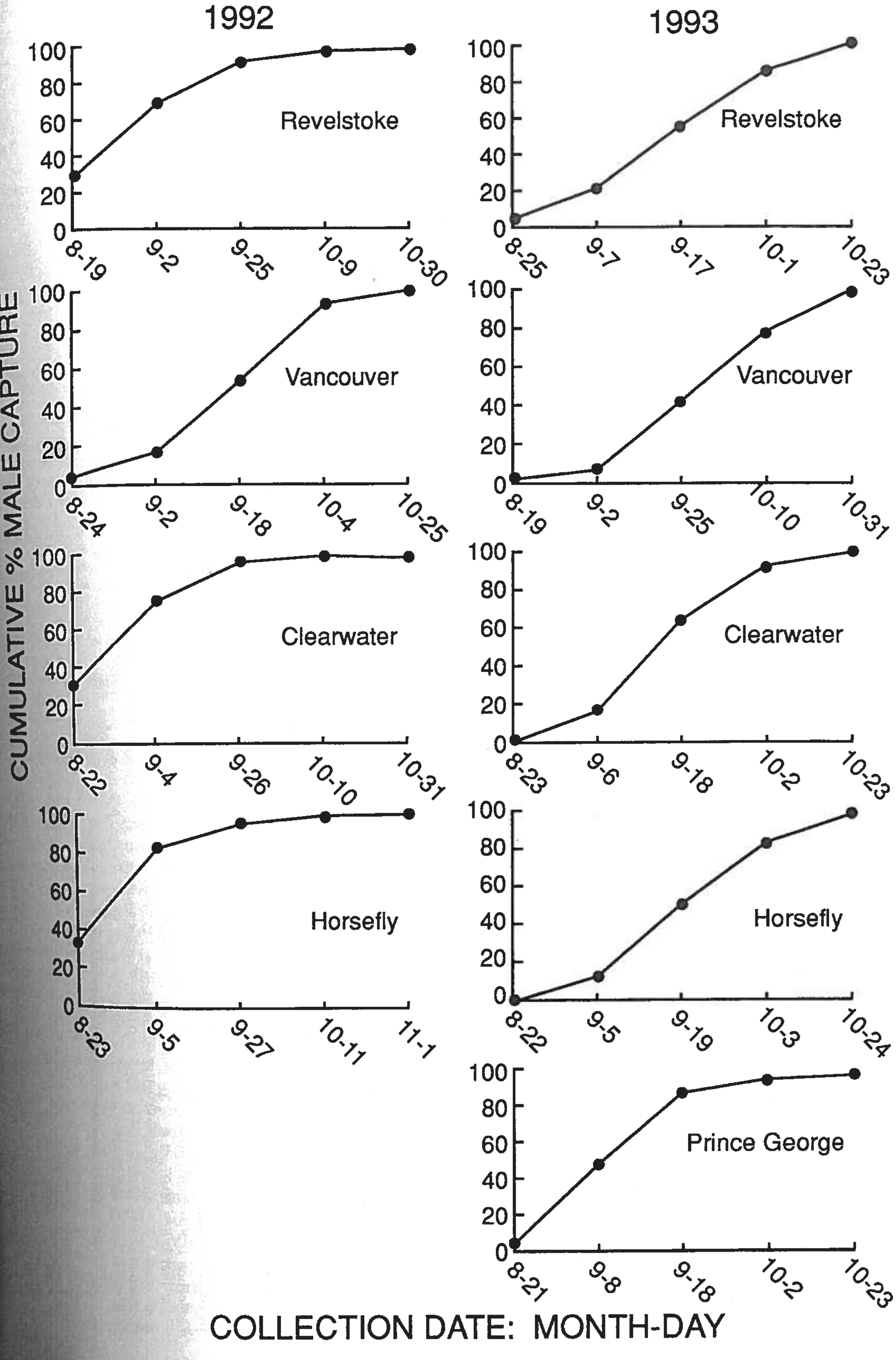

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Table 1. Mean ± SEM numbers of male western hemlock loopers captured in pheromone-baited traps, by dose and collection date (mo/d), 1992

Area and no. replicates	Dose, µg	Collections[a]				
		1 8/19–8/24	2 9/02–9/06	3 9/18–9/27	4 10/04–10/11	5 10/25–11/01
Revelstoke $n = 9$	0	113.4 ± 88.2b	153.4 ± 127.0c	10.3 ± 7.5d	3.3 ± 1.9d	0.2 ± 0.1d
	10	626.4 ± 338.0a	847.4 ± 169.8b	456.3 ± 121.3c	126.5 ± 36.4c	21.2 ± 4.5c
	100	796.6 ± 262.6a	2,733.3 ± 478.5a, b	1,749.9 ± 468.6b	1,268.1 ± 412.8b	197.6 ± 76.9b
	1,000	770.0 ± 162.8a	4,522.3 ± 348.3a	4,881.1 ± 297.8a	3,568.1 ± 491.4a	760.2 ± 122.0a
	10,000	1,538.1 ± 564.3a	4,997.8 ± 443.3a	5,610.0 ± 239.2a	4,039.0 ± 527.1a	1,431.5 ± 464.4a
Clearwater $n = 7$	0	69.7 ± 28.9c	41.7 ± 22.5c	1.1 ± 0.6d	1.3 ± 0.6d	0c
	10	630.4 ± 181.4b	1,049.3 ± 572.6b	408.0 ± 257.4c	57.4 ± 22.1c	2.71 ± 1.61c
	100	1,972.0 ± 314.2a, b	3,342.7 ± 714.9a	1,155.1 ± 252.2b	543.6 ± 226.3b	24.6 ± 10.6b
	1,000	3,476.0 ± 278.9a	5,525.1 ± 365.1a	2,617.3 ± 627.2a, b	1,485.7 ± 469.0a	90.3 ± 28.4a
	10,000	3,342.7 ± 512.9a	5,321.8 ± 546.6a	3,675.8 ± 853.5a	1,472.0 ± 457.3a	69.1 ± 21.4a
Horsefly $n = 3$	0	178.0 ± 80.7a	156.0 ± 73.1c	10.3 ± 7.4c		0.3 ± 0.3c
	10	773.7 ± 463.6a	1,189.7 ± 491.4b	269.0 ± 115.2b		3.0 ± 1.5b, c
	100	1,837.0 ± 20.0a	3,331.3 ± 131.2a	1,369.7 ± 434.3a		6.0 ± 4.6b, c
	1,000	1,809.0a	5,021.7 ± 665.7a	2,041.0 ± 502.7a		33.0 ± 15.6a, b
	10,000	1,485.3 ± 288.9a	4,854.3 ± 705.0a	3,021.7 ± 1,157.4a		76.3 ± 39.8a
Vancouver $n = 8$	0	0c	0c	0c	0d	0c
	10	3.0 ± 1.3b	11.4 ± 4.2b	30.1 ± 10.6b	32.6 ± 7.6c	6.1 ± 2.7b
	100	9.3 ± 3.2a	36.3 ± 12.7a	69.3 ± 23.7b	87.8 ± 35.7b, c	28.6 ± 17.6b
	1,000	11.1 ± 5.9a	74.6 ± 18.6a	221.5 ± 68.9a, b	279.5 ± 83.5a	98.4 ± 42.3a
	10,000	13.1 ± 4.8a	63.5 ± 11.9a	187.3 ± 33.7a	145.9 ± 33.3a, b	95.1 ± 35.1a

Within a region and collection period, means followed by the same letter are not significantly different, Bonferroni t test, $P < 0.05$, on data transformed by $\log_e(x + 1)$. Data from the Horsefly area, collection 4 are not included because of missing observations. The F values, degrees of freedom, and P values for the Revelstoke, Clearwater, Horsefly, and Vancouver study areas, respectively, by collection time are the following.

Collection 1: $F = 29.85$; df = 4, 30; $P = 0.0001$; $F = 43.90$; df = 4, 24; $P = 0.0001$; $F = 3.69$; df = 4, 5; $P = 0.0924$; $F = 14.77$; df = 4, 27; $P = 0.0001$.
Collection 2: $F = 59.97$; df = 4, 31; $P = 0.0001$; $F = 92.88$; df = 4, 22; $P = 0.0001$; $F = 69.86$; df = 4, 8; $P = 0.0001$; $F = 51.42$; df = 4, 27; $P = 0.0001$.
Collection 3: $F = 180.32$; df = 4, 31; $P = 0.0001$; $F = 145.61$; df = 4, 24; $P = 0.0001$; $F = 128.77$; df = 4, 8; $P = 0.0001$; $F = 65.31$; df = 4, 28; $P = 0.0001$.
Collection 4: $F = 237.57$; df = 4, 30; $P = 0.0001$; $F = 238.22$; df = 4, 30; $P = 0.0001$; $F = 87.75$; df = 4, 28; $P = 0.0001$.
Collection 5: $F = 225.28$; df = 4, 30; $P = 0.0001$; $F = 44.09$; df = 4, 24; $P = 0.0001$; $F = 13.02$; df = 4, 8; $P = 0.0014$; $F = 35.67$; df = 4, 27; $P = 0.0001$.

[a] Collections made at areas on different days, bounded by time specified.

Table 2. Mean numbers ± SEM of male western hemlock loopers captured in pheromone-baited traps, by dose and collection date (mo/d), 1993

Area and no. replicates	Dose, µg	Collections[a] 1 8/21–8/26	2 9/05–9/13	3 9/17–9/25	4 10/01–10/10	5 10/22–10/31
Revelstoke $n = 9$	0	5.7 ± 4.6c	9.1 ± 3.5c	154. ± 5.5c	9.4 ± 3.7c	8.7 ± 3.9c
	1	22.9 ± 13.2b	83.8 ± 19.4b	114.1 ± 33.3b	55.0 ± 16.3b	40.9 ± 14.5b
	10	112.1 ± 46.5a	577.4 ± 195.2a	1,031.8 ± 363.1a	933.7 ± 359.7a	476.0 ± 181.5a
Clearwater $n = 7$	0	0.3 ± 0.3b	0.1 ± 0.1b	1.3 ± 1.3b	0.1 ± 0.1c	0b
	1	0.7 ± 0.4a, b	12.4 ± 4.5a	47.0 ± 21.6a	26.2 ± 12.9b	10.7 ± 5.6a
	10	3.0 ± 1.3a	59.9 ± 27.7a	181.4 ± 83.4a	109.4 ± 49.7a	29.4 ± 8.7a
Horsefly $n = 6$	0	0a	0.7 ± 0.5b	2.5 ± 1.4c	1.0 ± 0.7b	0.8 ± 0.8c
	1	0a	2.5 ± 1.3b	14.5 ± 4.9b	4.7 ± 2.2b	3.5 ± 1.6b
	10	0.2 ± 0.2a	26.2 ± 13.8a	97.4 ± 22.9a	70.0 ± 14.7a	34.2 ± 12.0a
Vancouver $n = 7$	0	0	0b	0c	0c	0b
	1	0	5.3 ± 3.8b	14.3 ± 6.3b	14.3 ± 4.0b	4.0 ± 2.9b
	10	0	12.1 ± 4.9a	83.3 ± 24.0a	84.4 ± 29.5a	49.1 ± 36.0a
Prince George $n = 5$	0	13.6 ± 5.5b	112.2 ± 50.7b	107.4 ± 62.7b	15.3 ± 9.5b	9.8 ± 6.7b
	1	20.0 ± 14.3b	143.0 ± 7.9b	62.4 ± 11.9b	13.8 ± 2.0b	8.2 ± 2.1b
	10	151.4 ± 30.7a	1,403.4 ± 550.3a	1,303.0 ± 786.0a	231.4 ± 86.6a	153.6 ± 79.5a

Within a region and collection period, means followed by the same letter are not significantly different, Bonferroni *t* test, $P < 0.05$, on data transformed by $\log_e(x + 1)$. The *F* values, degrees of freedom, and *P* values for the Revelstoke, Clearwater, Horsefly, Vancouver, and Prince George study areas, respectively, by collection date are the following.

Collection 1: $F = 14.31$; df = 4, 26; $P = 0.0001$; $F = 6.50$; df = 2, 12; $P = 0.0122$; $F = 1.00$; df = 2, 10; $P = 0.4019$; $F = 7.74$; df = 2, 8; $P = 0.0135$.

Collection 2: $F = 38.28$; df = 4, 28; $P = 0.0001$; $F = 19.93$; df = 2, 12; $P = 0.0002$; $F = 35.61$; df = 2, 10; $P = 0.0001$; $F = 13.26$; df = 2, 11; $P = 0.0012$; $F = 20.02$; df = 2, 8; $P = 0.0008$.

Collection 3: $F = 55.18$; df = 4, 27; $P = 0.0001$; $F = 15.17$; df = 2, 11; $P = 0.0007$; $F = 26.15$; df = 2, 9; $P = 0.0002$; $F = 49.93$; df = 2, 12; $P = 0.0001$; $F = 13.42$; df = 2, 8; $P = 0.0028$.

Collection 4: $F = 56.90$; df = 4, 27; $P = 0.0001$; $F = 29.49$; df = 2, 12; $P = 0.0001$; $F = 40.15$; df = 2, 10; $P = 0.0001$; $F = 61.69$; df = 2, 12; $P = 0.0001$; $F = 12.54$; df = 2, 7; $P = 0.0049$.

Collection 5: $F = 14.92$; df = 4, 28; $P = 0.0001$; $F = 18.23$; df = 2, 12; $P = 0.0002$; $F = 53.99$; df = 2, 10; $P = 0.0001$; $F = 14.11$; df = 2, 12; $P = 0.0007$; $F = 10.53$; df = 2, 12; $P = 0.0057$.

[a] Collections made at areas on different days, bounded by time specified.

respond (Fig. 1), peak flight was preceded by relatively high temperatures. In previous studies (Hopping 1934), peak emergence of western hemlock looper adults coincided with low relative humidity and high temperature. Thomson (1952) correlated the occurrence of outbreaks of the western hemlock looper with low levels of precipitation before the onset of the outbreak.

Increase in capture of males with increasing sex pheromone dose is consistent with previous findings (Gries et al. 1993) and has been observed for many Lepidoptera (e.g., Baker et al. 1981, Turgeon et al. 1983, Sweeney and McLean 1990, Anshelevich et al. 1993). Similar captures of male western hemlock loopers at the 2 highest doses of 1,000 and 10,000 µg suggest that trap saturation may have occurred at these high doses. Dose-dependent increase and decrease (at high doses) in trap capture of male armyworms, *Pseudaletia unipuncta* (Haworth) (Turgeon et al. 1983), and eastern blackheaded budworms, *Acleris variana* (Fern.) (Gries et al. 1994), further suggest that peak attraction occurs at optimal (intermediate) pheromone doses. Increasing release rates of synthetic sex pheromone in a forest environment provoked male gypsy moths, *Lymantria dispar* (L.), to respond from increasingly greater distances but did not make them orient to the elevated pheromone sources (Elkinton et al. 1987).

Previously used (100 µg) cleaned and uncleaned unbaited Unitraps were equally unattractive to male western hemlock loopers (Gries et al. 1993). Capture of moths in unbaited control traps in 1993 may possibly be attributed to 1,000- and 10,000-µg lures in 1992 that had, despite assiduous cleaning, contaminated traps. Trap contamination from one season to the next was most readily observed at high population levels of the spruce budworm, *Choristoneura fumiferana* (Clemens) (Sanders 1992). At high population levels, a certain number of males simply blunder into unbaited traps (Roelofs and Cardé 1977, Sanders 1978). This could be a contributing factor in the high catches in control traps observed in the Prince George area (Table 2), where populations were at outbreak levels in 1993. In contrast, lack of statistical difference between control and 1-µg-baited traps in the Horsefly area (Table 2) at all collections except during peak flight suggests very low population levels in this study area in 1993.

Dose-dependent release rates from septa (Daterman 1982) are based on 1st-order kinetics, with release rates of a compound dependent on the amount of material remaining in the device

Table 3. Difference in numbers (mean ± SEM) of male western hemlock loopers captured in newly baited and original 1- and 10-μg baited Unitraps

Dates	Dose, μg	Lure type	No. males captured	P, T between lure type[a]
93-08-07–93-08-25	1	New	27.1 ± 16.8	
		New	22.3 ± 16.0	0.7500, 2.0
	10	New	51.9 ± 21.2	
		New	118.3 ± 60.7	0.2188, −8.0
93-08-25–93-09-07	1	New	71.7 ± 23.2	
		Original	80.3 ± 25.2	0.6875, −3.0
	10	New	372.3 ± 227.5	
		Original	534.4 ± 226.3	0.4688, −5.0
93-09-07–93-09-17	1	New	98.7 ± 38.3	
		Original	113.3 ± 40.5	0.3750, 6.0
	10	New	650.0 ± 260.1	
		Original	1,021.3 ± 439.4	0.5781, −4.0
93-09-17–93-10-01	1	New	102.7 ± 35.1	
		Original	63.1 ± 19.9	0.6875, 3.0
	10	New	346.9 ± 121.3	
		Original	1,116.9 ± 443.4	0.0156, −14.0
93-10-01–93-10-22	1	New	96.1 ± 29.6	
		Original	49.0 ± 17.4	0.1875, 8.5
	10	New	231.7 ± 75.8	
		Original	561.9 ± 224.4	0.1094, −10.0

[a] Wilcoxon signed rank test.

(Weatherston 1989). Characteristics of the bioactive chemicals, including molecular weight and chemical functionality, further modify release rates (Daterman 1982). Methylated hydrocarbons, such as the pheromone components of the western hemlock looper, are chemically inert (Fessenden and Fessenden 1986), contributing to the persistence of both the 1- and 10-μg lures throughout the 3-mo trapping period (Table 3). Hypothesizing temperature-dependent release rates, the cool 1993 summer (Fig. 1) may have prolonged the attraction of the lures (Daterman 1982). Lure age has been shown to influence the attractiveness of pheromone-baited traps in several systems (e.g., Hoyt et al. 1983, Sanders and Meighen 1987, Sweeney et al. 1990, Jansson et al. 1992, Anshelevich et al. 1993). The data in Table 3 suggest that in a monitoring system for the western hemlock looper, both 1- and 10-μg lures would remain attractive for an entire flight season. Because 10-μg lures give a better predictive index of immature stages in the subsequent generation (Evenden 1994, Evenden et al. 1995) this lure is recommended for use in a monitoring system.

Superiority of Unitraps over sticky traps (Table 4) was mainly caused by saturation of the 825-cm² sticky surface, which occurred when as few as 100 moths were captured. The efficiency of sticky traps generally decreases as the sticky surface becomes occupied with moths (Houseweart et al. 1981, Ramaswamy and Cardé 1982, Sanders 1986, Polavarapu and Seabrook 1992). In Prince George, trap

Table 4. Difference in numbers (mean ± SEM) of male western hemlock loopers captured in similarly baited sticky traps and Unitraps

Dates	Dose, μg	No. sites	Trap type	No. males captured	P, T between trap type[a]
			Collection 1		
93-08-07–93-08-25	0	18	Sticky	0.6 ± 60.3	
			Unitrap	6.1 ± 2.8	0.0469, 12.5
	1	16	Sticky	8.2 ± 3.0	
			Unitrap	17.7 ± 8.6	0.1580, 15.5
	10	20	Sticky	20.1 ± 4.5	
			Unitrap	85.3 ± 25.7	0.0154, 59.0
			Collection 4		
93-09-17–93-10-01	0	6	Sticky	2.8 ± 1.3	
			Unitrap	12.0 ± 4.5	0.1875, 6.0
	1	7	Sticky	12.0 ± 3.4	
			Unitrap	117.0 ± 37.6	0.0156, 14.0
	10	7	Sticky	68.1 ± 12.5	
			Unitrap	346.9 ± 121.3	0.0156, 14.0

[a] Wilcoxon signed rank test.

saturation with nontarget Diptera
occasions. The capture of nontarg
general debris often reduces the e
sticky traps (Ramaswamy and Card
tect or to monitor low moth popula
types are appropriate. However, if
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moderate-to-high levels (Housewe
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traps are required. In general, sti
much more difficult and time consu
than Unitraps.

Several conclusions can be draw
search that will directly facilitate th
of a monitoring program for the w
looper (Evenden et al. 1995) and
managers to detect changes in po
before defoliation is evident.

1) Within a wide range of dose
hemlock loopers demonstrate a
response to pheromone-baited tra

2) Lures containing 1 or 10 μg
5,11-dimethylheptadecane and 2,5
decane will remain attractive over
The 10-μg baited trap is recomme
a monitoring system because it be
size of the subsequent generation
Evenden et al. 1995).

3) Nonsaturating Unitraps are b
sticky traps for monitoring westerr
populations. Other nonsaturating t
be evaluated for their use in a m
for the western hemlock looper.

4) Seasonal trends in trap captu
ature do not track each other, b
preceded by high temperatures
thermal sums might be a good inc
set of western hemlock looper flig

A pheromone-based sampling
western hemlock looper could b
placing Unitraps baited with 10-
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2,5-dimethylheptadecane at sites
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weather conditions. Using such a
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than the current system of conc
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Acknowledgmen

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Survey of the Canadian Forest Servi
site establishment, R. Gries and L. J.
ser University Chemical Ecology R
technical assistance, and F. Belleva
University) for statistical advice. Fi
provided by the Canadian Forest Se
Simon Fraser University and the N
Engineering Research Council of C
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opers captured in newly baited and

les ed	P, T between lure type[a]
16.8	0.7500, 2.0
16.0	
21.2	0.2188, −8.0
: 60.7	
: 23.2	0.6875, −3.0
± 25.2	
± 227.5	0.4688, −5.0
± 226.3	
± 38.3	0.3750, 6.0
± 40.5	
± 260.1	0.5781, −4.0
± 439.4	
± 35.1	0.6875, 3.0
± 19.9	
) ± 121.3	0.0156, −14.0
) ± 443.4	
1 ± 29.6	0.1875, 8.5
0 ± 17.4	
.7 ± 75.8	0.1094, −10.0
.9 ± 224.4	

993). The data in Table 3 suggest that ing system for the western hemlock 1- and 10-μg lures would remain at- n entire flight season. Because 10-μg better predictive index of immature he subsequent generation (Evenden den et al. 1995) this lure is recom- use in a monitoring system. ty of Unitraps over sticky traps (Table ly caused by saturation of the 825-cm² ce, which occurred when as few as 100 captured. The efficiency of sticky traps lecreases as the sticky surface becomes vith moths (Houseweart et al. 1981, Ra- and Cardé 1982, Sanders 1986, Polavar- Seabrook 1992). In Prince George, trap

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No. males captured	P, T between trap type[a]
0.6 ± 60.3	0.0469, 12.5
6.1 ± 2.8	
8.2 ± 3.0	0.1580, 15.5
17.7 ± 8.6	
20.1 ± 4.5	0.0154, 59.0
85.3 ± 25.7	
2.8 ± 1.3	0.1875, 6.0
12.0 ± 4.5	
12.0 ± 3.4	0.0156, 14.0
117.0 ± 37.6	
68.1 ± 12.5	0.0156, 14.0
346.9 ± 121.3	

saturation with nontarget Diptera occurred on 2 occasions. The capture of nontarget insects and general debris often reduces the effectiveness of sticky traps (Ramaswamy and Cardé 1982). To detect or to monitor low moth populations, both trap types are appropriate. However, if quantitative estimates of populations are desired, particularly at moderate-to-high levels (Houseweart et al. 1981, Polavarapu and Seabrook 1992), nonsaturating traps are required. In general, sticky traps were much more difficult and time consuming to handle than Unitraps.

Several conclusions can be drawn from this research that will directly facilitate the establishment of a monitoring program for the western hemlock looper (Evenden et al. 1995) and enable forest managers to detect changes in population density before defoliation is evident.

1) Within a wide range of doses, male western hemlock loopers demonstrate a dose-dependent response to pheromone-baited traps.

2) Lures containing 1 or 10 μg of both isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane will remain attractive over the flight season. The 10-μg baited trap is recommended for use in a monitoring system because it better forecasts the size of the subsequent generation (Evenden 1994, Evenden et al. 1995).

3) Nonsaturating Unitraps are better suited than sticky traps for monitoring western hemlock looper populations. Other nonsaturating trap types should be evaluated for their use in a monitoring system for the western hemlock looper.

4) Seasonal trends in trap captures and temperature do not track each other, but peak flight is preceded by high temperatures. In the future, thermal sums might be a good indicator of the onset of western hemlock looper flight.

A pheromone-based sampling system for the western hemlock looper could be established by placing Unitraps baited with 10-μg lures of a 1:1 (vol:vol) ratio of 5,11-dimethylheptadecane and 2,5-dimethylheptadecane at sites before the flight starts in early August or late July, depending on weather conditions. Using such a system, monitoring would be easier and would provide data sooner than the current system of conducting egg sampling in October.

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Predictive Capabi
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ABSTRACT Eggs, larv
lugubrosa (Hulst), were
pheromone-baited Unitr
western hemlock and int
moth catches in traps ba
dimethylheptadecane on
pupal counts within the s
generation, suggesting th
predict future outbreaks.

KEY WORDS *Lambdi*

ONE OF THE potential uses of a
employing pheromone-baited tr
tative prediction of population
1988). There are 2 main metho
the relationship between numb
tured in traps and population d
between numbers of captured in
numbers of other stages of the
(Sanders 1988); and mark–rele
periments (Elkinton and Cardé
et al. 1983).

In many instances, predictive
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stages (Harris et al. 1982, Sand
these techniques are costly a
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the western hemlock looper
nually in British Columbia by
and Disease Survey (FIDS) of th
Service at a network of samplin
the province (Harris et al. 1982)
on samples of eggs (Kinghor
1958, Carolin et al. 1964), la
1982), and pupae (Shore 1989)
dict forthcoming outbreaks.

A validated pheromone-base
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tions and numbers of male bud

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