DEVELOPMENT OF A PHEROMONE-BASED DETECTION AND MONITORING TECHNIQUE FOR THE WESTERN HEMLOCK LOOPER, *Lambdina fiscellaria lugubrosa* (HULST) (LEPIDOPTERA: GEOMETRIDAE)

by

Maya L. Evenden

B.Sc. University of Victoria, 1991

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF PEST MANAGEMENT

in the Department

of

Biological Sciences

SIMON FRASER UNIVERSITY

April 1994

APPROVAL

Name: **MAYA LOUISE EVENDEN**

Degree: **Master of Pest Management**

Title of Thesis:

DEVELOPMENT OF A PHEROMONE-BASED DETECTION AND MONITORING TECHNIQUE FOR THE WESTERN HEMLOCK LOOPER, LAMBDINA FISCELLARIA LUGUBROSA (HULST) (LEPIDOPTERA: GEOMETRIDAE)

Examining Committee:

Chair: Dr. J. Webster, Professor

Dr. J.H. Borden, Professor, Senior Supervisor,
Department of Biological Sciences, SFU

Dr. G. Gries, Assistant Professor,
Department of Biological Sciences, SFU

Dr. G.A. Van Sickle, Research Scientist
Canadian Forest Service, Victoria, B.C.

Dr. S. Fitzpatrick, Research Scientist
Agriculture Canada, Vancouver, B.C.
Public Examiner

Date Approved 13 April 1994

PARTIAL COPYRIGHT LICENSE

I hereby grant to Simon Fraser University the right to lend my thesis, project or extended essay (the title of which is shown below) to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users. I further agree that permission for multiple copying of this work for scholarly purposes may be granted by me or the Dean of Graduate Studies. It is understood that copying or publication of this work for financial gain shall not be allowed without my written permission.

Title of Thesis/Project/Extended Essay

DEVELOPMENT OF A PHEROMONE-BASED DETECTION AND MONITORING TECHNIQUE FOR THE WESTERN HEMLOCK LOOPER, *Lambdina fiscellaria lugubrosa* (HULST) (LEPIDOPTERA : GEOMETRIDAE).

Author: _____
(signature)

_____
(name)

April 13, 1994.
(date)

ABSTRACT

A two component pheromone blend containing a 1:1 ratio of isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane was used in high-capacity, non-sticky Unitraps to monitor populations of the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera:Geometridae) at 27 sites (1992) and 34 sites (1993) throughout the Coastal Western Hemlock and Interior Cedar Hemlock biogeoclimatic zones of British Columbia. Rubber septa were loaded via hexane solution with 10, 100, 1000, and 10000 µg (1992) and 1 and 10 µg (1993) of the blend. One trap of each dose plus an unbaited control were suspended from trees in random order at each site, 1-2 m above the ground and 100 m apart. Immature stages of the western hemlock looper (eggs, larvae and pupae) were sampled and related to male moths captured in pheromone-baited traps at each study site. Pheromone-baited traps captured significantly more male moths than unbaited control traps. Catches in traps baited with 10 µg lures caught male western hemlock loopers throughout the three-month (August through October) flight season in both years; the seasonal trends in trap catches were not closely related to temperature. Male moths demonstrated a dose-dependent response to pheromone-baited traps except that response to the two highest doses (1000 and 10000 µg) was the same. In a trap-comparison experiment in 1993, Unitraps captured significantly more male moths than similarly baited sticky

traps in the control and 10 µg-baited traps at the beginning of the flight and in 1 and 10 µg-baited traps at mid-flight. In 1993, a declining trend in lure potency was evident but not significant for the 1 µg lures. No such trend was observed for the 10 µg lures. Male moth catches in 10 µg-baited traps were correlated with larval and pupal counts within the same generation and were predictive of egg counts in the subsequent generation, suggesting that pheromone-baited traps could be used to monitor populations and predict future outbreaks.

Acknowledgements

This project was made possible by the contributions of many people. Firstly, I would like to thank Dr. J.H. Borden for his tremendous enthusiasm, support and advice in all aspects of this work from its inception to completion. He has provided a stimulating and enjoyable learning environment throughout my involvement in the M.P.M. program. I would also like to thank Drs. G.A. Van Sickle and G. Gries for advice and support throughout this project. I am indebted to the Forest Insect and Disease Survey of the Canadian Forest Service, and in particular, Messrs. R. Erickson, N. Humphreys, P. Koot, A. Stewart, R. Turnquist and C.S. Wood, who were instrumental in site establishment, sampling of immature stages, and providing me with sticky traps. I would also like to thank Dr. J. Li for synthesizing the pheromone components tested, Ms. R. Gries for loading the lures, Ms. L.J. Chong for logistic support and Mr. F. Bellevance for statistical advice. Fellow M.P.M. students and members of the Borden/Winston lab provided invaluable technical and moral support throughout this project. I am grateful to the many friends, relatives and colleagues who accompanied me during my field work. Finally, I would like to thank my family, Steven, Len, Polly, Kirstin and Matthew for their support, understanding, assistance in field and lab work and overall enthusiasm and interest in this work. This work was funded by the Canadian Forest Service (Green Plan), Simon Fraser University and the Natural Sciences and Engineering Research Council of Canada.

Table of Contents

List of Tables

List of Figures

1.0 GENERAL INTRODUCTION: THE WESTERN HEMLOCK LOOPER

The western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera:Geometridae), is an important defoliating pest of conifers in western North America. 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).

1.0.1 *Distribution*

The species *Lambdina fiscellaria* is transcontinental in distribution and is comprised of three distinct subspecies (McGuffin 1987). *Lambdina fiscellaria fiscellaria* (Guenée), the eastern hemlock looper, occurs east of the Rocky Mountains; the other two subspecies, *Lambdina fiscellaria somniaria* (Hulst), the western oak looper, and *Lambdina fiscellaria lugubrosa* are found west of the Rocky Mountains, the former feeding on *Quercus spp.* and the latter feeding principally on *Tsuga* and *Abies spp.* (McGuffin 1987). *L.f. lugubrosa*, is found throughout western North America (Erickson 1984). It is very destructive in the coastal forests of Washington, Oregon and British Columbia, and less so in the interiors of these areas and in Alaska, Idaho and Montana (Furniss and Carolin 1977). However, in British Columbia recent outbreaks have occurred most frequently in the interior

of the province (Shore 1990). In British Columbia it is found south of 56° N latitude (Erickson 1984) where populations are most prominent in the Coastal Western Hemlock and Interior Cedar Hemlock Biogeoclimatic Zones and are also found in the Interior Douglas-fir and Sub-boreal Spruce Zones (Harris *et al.* 1982).

1.0.2 *Biology*

The preferred host of the western hemlock looper in British Columbia is western hemlock, *Tsuga heterophylla* (Raf.) Sarg. (Shore 1989, Erickson 1984, Harris *et al.* 1982). However, this insect will feed on other coniferous species and on almost any foliage during outbreaks (Erickson 1984, Hopping 1934). Outbreaks occur primarily in mature and overmature western hemlock stands, but have been reported in healthy second growth stands, 80-100 years old (Lejeune 1975).

Eggs are laid in September and October (Erickson 1984), singly (Shore 1989) or in small groups of 2 to 10 eggs (Hopping 1934), on substrates such as moss and lichen, in bark crevices on the trunk and branches of trees (Shore 1989), and on foliage of trees (Hopping 1934). Oviposition may occur on litter on the forest floor, but only when moth numbers are high at the peak of an infestation (Hopping 1934). Hatching occurs in the spring, and young larvae commence feeding at the top of the crown (Erickson 1984). There are six larval

instars (Erickson 1984). First and second instars are light feeders on buds, whereas later instars are wasteful feeders on foliage (Furniss and Carolin 1977). Larvae drop vertically on silken threads, to the forest floor, or to lower branches of the host tree in August and September (Furniss and Carolin 1977). Pupation occurs in crevices in the bark, in moss or lichen, or under debris on the forest floor and generally lasts between 10 and 14 days (Furniss and Carolin 1977, Erickson 1984). Adults generally eclose in the evening and during the night (Hopping 1934), fly and mate from late August to mid October (Erickson 1984). Males have been reported to emerge first and outnumber females (Hopping 1934). There is one generation annually (Furniss and Carolin 1977).

1.0.3 *Damage*

Defoliation by the western hemlock looper was first reported in 1889-91, in two counties in Oregon (Furniss and Carolin 1977) and in British Columbia in 1911 at Stanley Park in Vancouver (Harris *et al.* 1982). Between 1911 and 1980, outbreaks occurred eight times at one or more of nine locations in British Columbia (Harris *et al.* 1982). Since then outbreaks have occurred in several areas: Kamloops Forest Region (1983-84)(Koot and Hodge 1992); Cariboo Forest Region (1984)(Erickson and Ferris 1992); Nelson Forest Region (1982-84)(Unger and Stewart 1992); Prince George Forest Region (1983)(Humphreys and Ferris 1992); and in the Vancouver Forest

Region (1987-88)(Van Sickle and Wood 1988, Van Sickle and Wood 1989). In 1990, 1115 ha were defoliated by the western hemlock looper throughout the province (Wood and Van Sickle 1991). Defoliation increased substantially in 1991 to 50 000 ha in the Cariboo and Nelson Forest Region, greater than 36 000 ha in the Kamloops Forest Region, and defoliation was noted over 250 ha in the Prince George Forest Region near McBride (Wood and Van Sickle 1992). An overall increase in defoliation to 186 000 ha throughout the province occurred in 1992 (Wood and Van Sickle 1993a). The area defoliated in 1993 declined to 92 750 ha province-wide (Wood and Van Sickle 1993b).

Since 1911 outbreaks have occurred at 4-17 year intervals (Harris *et al.* 1982), and persisted for 3-5 years (Hopping 1934; Harris *et al.* 1982; Furniss and Carolin 1977). They generally occur at low elevations, particularly in valley bottoms (Kinghorn 1954; Jardine 1969; Lejeune 1975; Erickson 1984). Collapse of epidemic populations is attributed to predators, disease, starvation and weather (Humphreys and Ferris 1992). Hopping (1934) bred 3 dipteran and 11 hymenopteran parasites, and 2 fungal pathogens, from immature stages of the western hemlock looper. A polyhedral virus has also been implicated in the decline of epidemic populations (Jardine 1969; Furniss and Carolin 1977; Harris *et al.* 1982; Erickson 1984).

1.0.4 *Monitoring Techniques Used In British Columbia*

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). Samples of eggs (Kinghorn 1952; Thomson 1958; Carolin *et al.* 1964), larvae (Harris *et al.* 1982) and more recently pupae (Shore 1989) have been used.

Egg sampling is preferred for estimating population trends of the western hemlock looper because eggs remain in place without declining in numbers over the winter (Shore 1990). Eggs are collected from 100 g samples of a lichen, *Alectoria spp.*(Shore 1990), the major oviposition site of the moth, especially in the interior of the province (Thomson 1958). Kinghorn (1952) suggested that butt sampling was adequate during outbreaks and noted that oviposition was heaviest in dense mosses sampled in coastal forests. Thomson (1958) found the greatest density of eggs on the bole of the mid and upper crown of felled trees and suggested that sampling could be restricted to these areas. Carolin *et al.* (1964) found the best sampling units for detecting looper infestations in coastal forests of Oregon to be mossy log surfaces and bole sections at breast height. Shore (1990) showed that there was no significant difference in egg numbers

obtained from low, mid or high-crown samples in the interior of British Columbia and concluded that representative samples could be obtained using pole pruners to collect lichen from the lower crown. Methods used for separating eggs from lichen samples (Condrashoff 1967, Eidt and Cameron 1970, Shepherd and Gray 1972, Otvos and Bryant 1972, and Gray *et al.* 1973) include a destructive method using hot water or non-destructive methods using chlorine bleach or sodium hydroxide (Shore 1989); the non-destructive methods should be used if eggs are to be examined closely for parasitism (Shore 1990).

Larvae are sampled by the three-tree beating method (Harris *et al.* 1972), in which larvae dislodged with a 2.75 m long pole from three western hemlock trees per location fall onto a 2.10 x 2.75 m sheet placed beneath each tree. The average number of larvae per tree and the percent positive collections are used to determine population trends (Harris *et al.* 1982). Harris *et al.* (1972) found that this method of sampling forest defoliators gave a satisfactory indication of population trends, but weather conditions strongly influenced the samples.

Pupal traps made of burlap strips wrapped around the lower bole of the tree are a satisfactory means for collecting pupae of the eastern hemlock looper (Otvos 1974). In British Columbia numbers of western hemlock looper sampled by this method were significantly related to the subsequent numbers of

viable eggs laid on lichen in the trees (Shore 1989). It was suggested that pupal sampling may be a useful management tool as it gives an earlier indication of population levels than egg sampling (Shore 1989).

1.0.5 *Sex Pheromone of the Western Hemlock Looper*

The presence of a sex pheromone emitted by female western hemlock looper moths was demonstrated by Ostaff *et al.* (1974a,b) who observed the calling behavior of the female moth and captured males in traps baited with virgin females. Gries *et al.* (1993) identified the pheromone as a blend of three methylated-hydrocarbons: 5,11-dimethylheptadecane (5,11), 2,5-dimethylheptadecane (2,5) and 7-methylheptadecane (7). In trapping experiments (5,11) was the most attractive component to male moths; attraction was enhanced with the addition of (2,5) or (7) and was greatest when all components were combined (Gries *et al.* 1993). Li *et al.* (1993a) found that only the (5*R*,11*S*) stereoisomer of (5,11), resulted in electrophysiological responses by male eastern and western hemlock looper antennae, and concluded that this was the only stereoisomer of this component produced by females of these species. Similarly, only the (7*S*) and (2,5*S*) enatiomers of (7) and (2,5), respectively were synergistic components of the western hemlock looper sex pheromone (Li *et al.* 1993b). The western hemlock looper pheromone blend differs from the two component blend of (5,11) and (2,5) of the eastern hemlock

looper (Gries *et al.* 1991) which supports their taxonomic division.

1.1 Objective

The objective of this study was to develop a pheromone-based monitoring system that can determine the temporal and spatial occurrence of the western hemlock looper and can predict incipient outbreaks.

2.0 DEVELOPMENT OF A PHEROMONE-BASED SAMPLING SYSTEM

Pheromone-based sampling of insect populations can have two main objectives: 1) the detection of the presence and distribution of a population; and 2) monitoring populations by the determination of population density with respect to a threshold (e.g. an economic impact or action threshold). Pheromone-baited traps are useful monitoring tools because they catch selectively at low population densities, are easy to use, capture relatively few or no non-target species, are generally cost effective, and can be used locally by individual producers or over a vast area (Wall 1989).

The development of pheromone-based monitoring systems for insect pests is generally initiated after a specific pheromone blend has been identified. Traps baited with virgin females can be used to monitor populations [e.g. for the almond seed wasp, *Eurytoma amygdali* (Enderlein)(Katsoyannos *et al.* 1992)], but this introduces uncertainty because of individual variation between bait insects, and is very labour intensive.

Factors which influence the ability of pheromone-baited traps to monitor populations of a given species include: 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 MaCaulay 1976; Houseweart *et al.* 1981; Ramaswamy and Cardé 1982; Angerelli and McLean 1984; Sanders 1986,1992; Jansson *et al.* 1992; Polavarapu and Seabrook 1992); 7) trap position (Lewis and MaCaulay 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 the cost of monitoring (Sanders 1992).

2.0.1 *Synthetic Pheromone*

Characteristics of the synthetic pheromone blend are crucial in the development of a monitoring system. The ratio of the various components, the dose, and the completeness of the pheromone blend (Linn *et al.* 1987) can alter attraction significantly (Roelofs 1978).

Male moths respond to a range of ratios and release rates of pheromone blends which approximate the female produced pheromone blend (Baker *et al.* 1981). Roelofs (1978) suggested that the sequence of behavioral events resulting in attraction of males to a pheromone source is invoked by a range of ratios and doses bordered by a lower threshold for flight activation

and a higher threshold of disorientation. This hypothesis was based on binary pheromone blends of geometric isomers and it was acknowledged that blends with more components would present a more complicated scenario (Roelofs 1978). In a wind tunnel, the complete range of behavioral responses by male Oriental fruit moths, *Grapholitha molesta* (Busck), including flight, upwind flight, wing fanning close to the pheromone source and hairpencilling was observed only over a narrow range of ratio and dose, which corresponded to reduced field captures of males at ratios and doses at the extremes of the testing range (Baker *et al.* 1981).

For many Lepidoptera, males are most responsive in trapping studies to the complete blend of the pheromone components. Examples of this phenomenon include recent field studies on the western hemlock looper (Gries *et al.* 1993) and the cranberry girdler, *Crysoteuchia topiaria* (Zeller) (Kamm *et al.* 1989). Sweeney *et al.*(1990a) found that the entire known pheromone blend of the western spruce budworm, *Choristoneura occidentalis* (Freeman), induced a greater number of males to fly upwind and land at the lure than the major component alone in flight tunnel bioassays, but trap captures in the field did not differ between the known blend and the major component alone. The entire pheromone blend of the Oriental fruit moth was shown in field studies to act as a whole to elicit optimal sensitivity over the entire response range (Linn *et al.* 1987). The active space of the Oriental fruit moth pheromone was subsequently shown in field

bioassays to vary with different blend ratios and temperature (Linn *et al.* 1991). The entirety and ratio of the blend used in a pheromone-based monitoring system may also influence the specificity of the trap. Pheromone-baited traps for the velvetbean caterpillar, *Anticarsia gemmatalis* (Hübner), also captured male *Mocis spp.*; manipulation of ratio and dose of the two components increased the trap specificity (McLaughlin and Heath 1989). Because male moths are responsive to pheromone blends over a range of doses (Roelofs 1978) the selection of the dose to be used in a monitoring system will depend on several factors (Jansson *et al.* 1992), including: 1) cost of formulation; 2) time required to process the samples at a given dose; 3) effect of dose on trap saturation; and 4) effect of dose on the sampling range of the trap. Concentrations of pheromone that greatly exceed the natural release rate of the virgin female are undesirable as they can alter male behavior and trap catch (Baker *et al.* 1981).

2.0.2 *Lure*

For monitoring systems which compare catches among locations and years, a dispenser that performs consistently and provides a constant release rate over the trapping period is preferred (Sanders and Meighen 1987; Wall 1989). Dispenser type affects the longevity of the lure, release rate of the pheromone over time, and the stability of the pheromone components (Sanders 1989). Five types of dispenser

containing a 95:5 ratio of (*E:Z*)-11-tetradecenal evaluated for their usefulness in monitoring spruce budworm populations showed clear differences in attraction of males over the flight period (Sanders and Meighen 1987). However, Ramaswamy and Cardé (1982) found little difference in attraction to spruce budworm males among five different lure types. The effectiveness of the lure can vary among trap types. The efficiency of seven types of lures tested to attract male *Heliothis virescens* (F.) did not vary when tested in cone traps but showed differing attractiveness in bucket traps (Kehat and Dunkelblum 1993). Rubber septa are the most widely used pheromone-release devices by researchers. They are readily obtained, easily loaded with pheromone and their efficacy is considered to be the industry standard (Weatherston 1989).

2.0.3 *Trap Type, Position and Density*

The trap type, position, and density are critical in the establishment of a monitoring system. Traps used for insect monitoring should be cheap, durable and easy to set up, and examine or empty (Wall 1989). Trap structure may determine the characteristics of the pheromone plume and the resultant capture of males (Lewis and Macaulay 1976; Angerelli and McLean 1984; Sanders 1986; Elkinton *et al.* 1987). For example, male pea moths, *Cydia nigricana* (Steph.), under field conditions, respond best to elongated plumes (Lewis and

Macaulay 1976). A common approach is to determine empirically the trap type that will catch a 'representative' number of insects without becoming saturated (Sanders 1986; Polavarapu and Seabrook 1992).

In general, pheromone-baited traps can be categorized into two types: sticky traps, which capture insects on a sticky adhesive material, and non-sticky, high-capacity traps, which capture insects with the aid of an added killing agent (Sanders 1989). High-capacity, non-saturating traps were found to be less efficient in the capture of spruce budworm males than Pherocon® 1CP sticky traps when tested in a wind tunnel (Sanders 1986), and at low population densities in the field (Ramaswamy and Cardé 1982). However, in field applications at moderate to high spruce budworm population densities, sticky traps become saturated, resulting in inactivation of the trap (Houseweart *et al.* 1981). Other important characteristics of a trap include ease of entry by the insect, its ability to prevent escapes (Ramaswamy and Cardé 1982) and in some instances trap color (Mitchell *et al.* 1989). Drawbacks of non-saturating, re-useable traps include: 1) possible repellency of the killing agent and accumulated dead insects (Sanders 1986); 2) the need for cleaning between uses to remove pheromone contaminants (Sanders 1992); and 3) provision of storage space (Sanders 1992).

There are three major considerations for trap placement:

height, density and position with respect to surrounding vegetation (Wall 1989). The height at which pheromone-baited traps are placed can markedly influence the numbers of males captured (Lewis and Macaulay 1976; McNally and Barnes 1981; Hoyt *et al.* 1983; Howell *et al.* 1990; Sanders 1992). McNeil (1991) suggests that the relative efficacy of traps located at different heights could vary daily if insects partition their flight in response to weather conditions. The physical nature of the habitat and the degree to which objects deflect or absorb the pheromone plume can also alter trap efficiency (McNeil 1991). For example, catches of spruce budworm males were found to increase with the amount of adjacent foliage as well as increased trap height (Sanders 1992).

The effectiveness of traps in a monitoring system can be altered by competition from other pheromone sources including calling feral insects and other synthetic lures (McNeil 1991). Houseweart *et al.* (1981) found that independence of trap catches in monitoring populations of spruce budworm required that traps be spaced at least 40 m apart.

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

2.1 METHODS AND MATERIALS

2.1.1 *Site Establishment*

In July 1992, 27 study sites (Table 1) were established, in the Coastal Western Hemlock and Interior Cedar Hemlock biogeoclimatic zones (Meidinger and Pojar 1991), throughout southern British Columbia. Sites of low medium or high infestation levels were selected on the basis of 1991 FIDS data, as well as current and historical information provided by FIDS rangers. Sites established in 1992 were in: the Vancouver Region[1] (Fraser Valley/Lower Mainland area)(8 sites), the Nelson Region (Columbia River drainage near Revelstoke)(9 sites), the Kamloops Region (Thompson River drainage near Clearwater)(7 sites); and the Cariboo Region (south side of Horsefly Lake)(3 sites). These study areas are henceforth referred to as Vancouver, Revelstoke, Clearwater and Horsefly.

In June 1993, an additional eight sites were established, in the Cariboo Region (as above) (3 sites) and in the Prince George Region (Robson Valley near McBride to Prince George)(5 sites), the latter area henceforth referred to as Prince George. All five sites in Prince George had outbreak population levels. One site in Vancouver was abandoned in

[1]Region refers to one of six administrative Forest Regions of the British Columbia Forest Service.

Table 1. Location and characteristics of sites used in British Columbia for testing of pheromone-based monitoring of western hemlock looper.

Area	#	Long.(W)	Lat.(N)	Elev. (m)	Species	Age* (yr)	Defoliation (1993)
Vancouver	1	121°36′	49°18′	50	Broadleaf maple White Birch Douglas-fir Western hemlock	101-120	none
	2	122°0′	49°22′	90	Douglas-fir Western hemlock Red alder	81-100	none
	3	122°15′	49°17′	130	PARK		none
	4	122°25′	49°15′	100	PARK		none
	5	122°29′	49°17′	45	PARK		none
	6	122°35′	49°13′	30	Western hemlock Douglas-fir Western redcedar	81-100	none
	7	122°32′	49°20′	225	Douglas-fir Western hemlock Western redcedar	101-120	none
	8	122°59′	49°26′	130	Western hemlock Douglas-fir Western redcedar	61-80	none
Revelstoke	1	117°56′	50°39′	345	Western hemlock	141-250	none
	2	118°12′	50°56′	505	Western hemlock Western redcedar	251+	trace
	3	118°28′	51°28′	470	Western hemlock	141-250	trace
	4	118°12′	51°28′	460	Western hemlock	251+	none
	5	118°35′	51°28′	450	Western hemlock	141-250	trace

	6	118°37′	51°50′	440	PRIVATE		none
	7	118°25′	52°05′	640	Western hemlock Western redcedar	81-100	none
	8	117°50′	51°08′	550	Western hemlock	251+	light
	9	118°05′	51°01′	430	Western hemlock	251+	trace
Clearwater	1	119°15′	51°55′	610	Douglas-fir White pine Western hemlock	141-250	none
	2	119°20′	52°05′	840	Western hemlock Western redcedar	251+	none
	3	119°20′	52°10′	695	Western hemlock Western redcedar	251+	none
	4	119°15′	52°10′	875	Western hemlock Western redcedar	251+	none
	5	119°15′	51°45′	715	Western hemlock Western redcedar	251+	none
	6	120°15′	25°00′	715	PARK		none
	7	120°15′	52°10′	630	PARK		none
Horsefly	1	121°45′	52°27′	845	Western hemlock Western redcedar Douglas-fir	251+	none
	2	121°45′	52°27′	875	Western redcedar Western hemlock	251+	none
	3	121°45′	52°28′	900	Western redcedar Western hemlock	251+	none
	4	121°47′	52°28′	920	Western redcedar Western hemlock	251+	none
	5	121°40′	52°29′	920	Western redcedar Western hemlock	251+	none
	6	121°39′	52°30′	1070	Western redcedar Western hemlock Balsam	141-250	none

Prince George	1	122°00′	54°00′	705	Western redcedar Western hemlock Spruce	251+	-
	2	122°30′	54°45′	735	Spruce Balsam Western hemlock Western redcedar	141-250	-
	3	121°00′	53°45′	755	Western redcedar Western hemlock	251+	94%
	4	121°45′	53°45′	775	Western hemlock Western redcedar	251+	43%
	5	121°30′	53°30′	860	Western redcedar Western hemlock Spruce	251+	90%

[a]Predominant species and age of stand taken from B.C. Forest Service cover maps, not available for parks or private land.

1993 due to excessive vandalism in 1992.

At each site the elevation was measured using an altimeter. The stand composition and age were obtained from B.C. Ministry of Forests Forest Cover Maps. FIDS rangers provided 1993 defoliation estimates. Weather data from stations in close proximity to study sites were obtained from the B.C. Ministry of Forests, Protection Branch.

2.1.2 *Dosage*

A two component pheromone blend containing a 1:1 ratio of isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane was synthesized in the summer of 1992 by J. Li (Department of Chemistry, Simon Fraser University). This two component pheromone blend (the entire known blend for the eastern hemlock looper) was used in place of the more attractive three component blend or the binary mixture of 5,11-dimethylheptadecane and 7-methylheptadecane so that a lure could be developed for both the western and eastern hemlock looper trapping systems. This blend was loaded into rubber septa (Sigma Chemical Co., St.Louis, Missouri) in hexane solution at doses of 10, 100, 1000, and 10000 µg in 1992, and 1 and 10 µg in 1993. Rubber septa were chosen as dispensers because they were readily available and are convenient for research purposes as they can be easily loaded with different doses and blends of pheromone. Thirty (1992) or 35 (1993)

septa marked with a dose-specific colored pin were impregnated with pheromone. Lures were mounted on plastic lure holders for use in high-volume, non-sticky Unitraps (Pherotech Inc. Delta, B.C.). Unitraps were used in this study as they were shown to capture male western hemlock loopers effectively in previous studies in British Columbia (Krannitz 1992; Gries *et al.* 1993) and they are available locally. Lures of each dose were kept separated in glass jars or double-bagged Ziploc freezer baggies (Dow Chemical Company, Paris, Ontario), and were held at 0° C until they were transported in refrigerated containers to study sites.

Prior to use, traps were washed in soap and water, soaked in hexane, rinsed and allowed to dry in the sun. Lures were hung below the lids of the Unitraps. To avoid cross contamination, the septa were loaded by handling the plastic lure holders only; the rubber septa were not touched. Traps were baited on site, and the baits remained in the same traps for the duration of the flight season.

At each site (Table 1), from 29 July - 2 August, 1992, one trap of each of the 10, 100, 1000, and 10000 µg lures plus one unbaited trap were suspended from trees in random order, along the edge of the forest, 1-2 m above the ground and at least 100 m apart. The 1-2 m height was successfully used in previous pheromone-trapping studies for the western hemlock looper (Krannitz 1992; Gries *et al.* 1993). Traps were hung at

least 100 m apart to avoid trap interference. One cube, approximately 1 cm^3, of solid-formulated dichlorovos (Green Cross Co., Mississauga, Ontario) was placed in each trap, to kill captured males. This was later replaced by two cubes at each subsequent moth collection. In 1993, three Unitraps were hung as in 1992 at each site from 7-11 August. Two traps were baited with either 1 or 10 µg lures; one was left as an unbaited control.

In both years male moths were collected five times at 2-3 week intervals, throughout the flight season from mid-August to the end of October (1992 and 1993). Moths were stored in plastic bags at 0° C until they were counted. Male moths were readily identified as western hemlock loopers by the presence of two sharply defined sinuate crosslines on the forewing (McGuffin 1987). An unidentified noctuid species was occasionally discovered in pheromone-baited traps and was discarded from the sample. Other non-target insects occasionally found in traps included beetles in the family Silphidae and a Trichoptera species.

2.1.3 *Lure Longevity*

In 1993 a lure longevity experiment was conducted at seven sites in the Revelstoke area. Five Unitraps were hung at least 100 m apart at each site, two traps containing 1 µg lures, two traps containing 10 µg lures, and one unbaited

control trap. Lures were prepared and handled as described above, except that at each collection (25 August, 7 September, 17 September, and 10 October, 1993) lures were replaced with a freshly-loaded lure in one of the traps at each dose level, while the other traps remained with the same lures throughout the flight season. Male moths were collected, stored and counted as above.

2.1.4 *Trap Type*

In 1993, an experiment comparing Unitraps and sticky traps was conducted at all study sites over the first collection period (7-25 August). Sticky traps consisted of 2 L milk cartons which had been coated internally with Bird Tanglefoot (The Tanglefoot Company, Grand Rapids, Michigan), and reshaped into a three-sided trap with open ends and hung long axis parallel to the ground using wire. The total exposed sticky surface area was 825 cm^2. Six traps were deployed at each study site in the Vancouver, Clearwater, Horsefly, and Prince George areas as follows: three Unitraps, with 1 or 10 μg baits or unbaited, and three sticky traps, identically baited. The traps were hung from trees, in random order, 1-2 m high and 100 m apart. Sticky traps were also placed in the Revelstoke area, following the above protocol but there were eight traps at each site as the lure longevity trial was conducted there. Sticky traps were placed at sites at the same time as the Unitraps (7-11 August) and were taken

down at the first collection (21-25 August) and transported to the laboratory for counting of captured moths. A second experiment was conducted at seven sites in the Revelstoke area in the mid-flight period (17 September - 1 October). Sticky traps containing freshly loaded lures (1 and 10 μg) and one unbaited control were placed in the same locations used in the first experiment.

2.1.5 *Statistical analysis*

Moth catches in the dose experiments were transformed by $\log_e(x+1)$ to ensure equal variances (Zar 1984), and then subjected to ANOVA followed by Bonferroni t-tests ($\alpha=0.05$) to compare means (SAS Institute Inc. 1988). The double split plot randomized complete block design (Winer *et al.* 1991) resulted in a significant three-way interaction among geographic area, time of collection and dose of pheromone used. Therefore, analysis for moth catches was divided into each of the four (1992) or five (1993) regions for each of the five trapping intervals.

To determine if a trend was evident in the numbers of males captured over time in traps baited with the newly-loaded and original lures, exposure durations (collection periods 1 through 5) were regressed (SAS Institute Inc. 1988) against the percentage of male moths captured during each collection period in traps baited with each type of lure at each dose.

Percentages of male moths were transformed by arcsin $\sqrt{x}$ to adjust for non-normal distributions (Zar 1984).

Male moth captures in sticky traps and Unitraps were compared by a Wilcoxon Rank Sum Test (SAS Institute Inc. 1988), due to non-normal distributions of male moth catches (Zar 1984). In the first experiment, data collected in the Vancouver and Horsefly areas were omitted from analysis because the flight had not started at the time of the experiment. In the second experiment catches in sticky traps were compared to those in freshly-baited Unitraps in the lure potency experiment so the potency of the baits was equal.

2.2 RESULTS AND DISCUSSION

2.2.1 *Seasonal Flight Trends*

Unitraps baited with various doses of the two component blend were attractive to male western hemlock loopers throughout the flight period. Examination of the seasonal trends for the 10 µg-baited traps (Fig. 1) disclosed that the onset, peak and termination of flight activity varied among regions and between years. The flight pattern did not track the mean daily temperature between collection periods but peak flight in all instances was preceded by temperatures in the 20-25°C range. Hopping's (1934) studies showed that 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 prior to the onset of the outbreak. In all regions and in both years the decreasing temperature line crosses the flight curve indicating that flight activity diminished at a different rate than 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 traps should be maintained in the field until the beginning of October to ensure that ~80% of the flight is sampled (Fig. 2).

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 - 2 August, 1992 and 7-11 August, 1993.

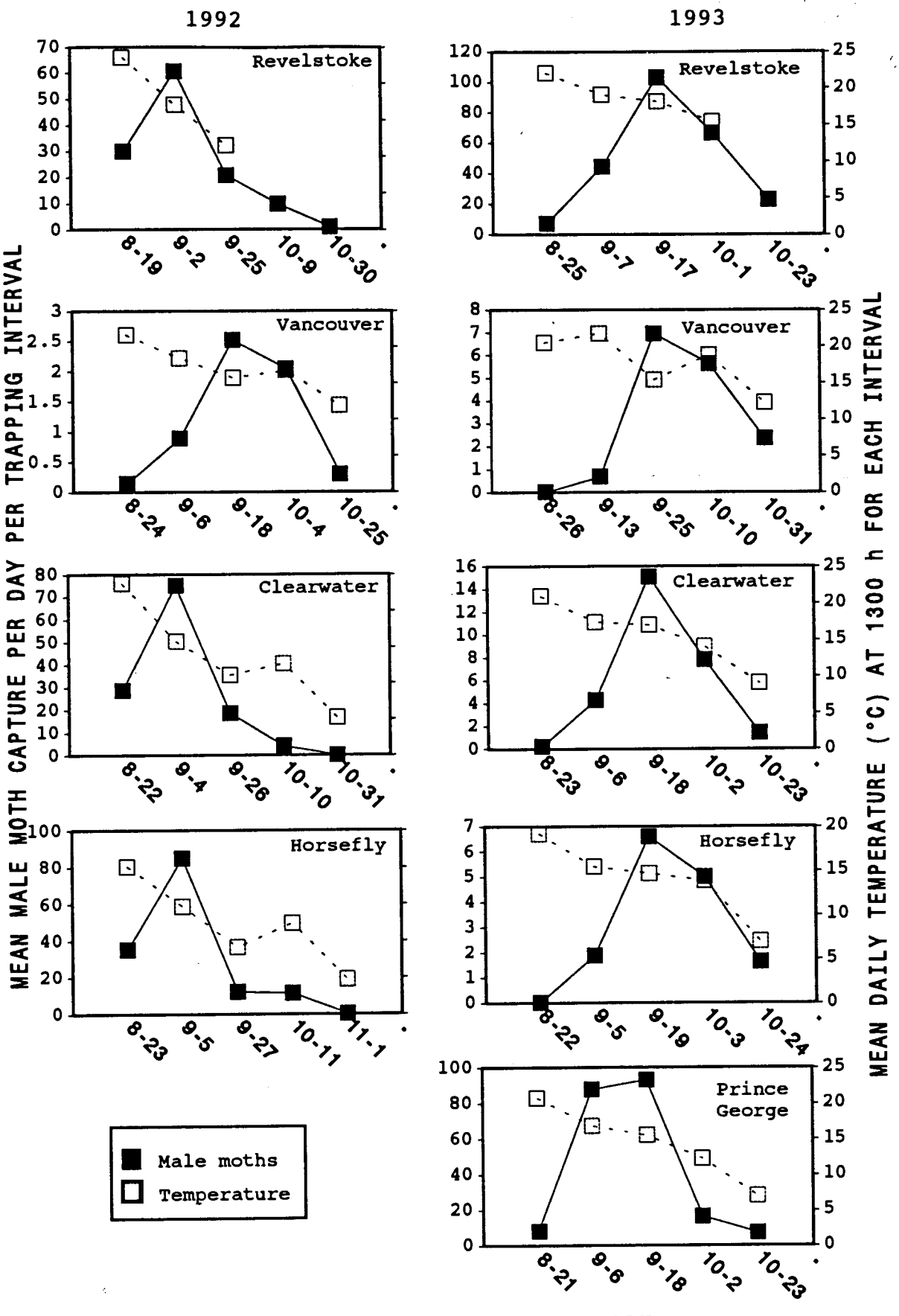
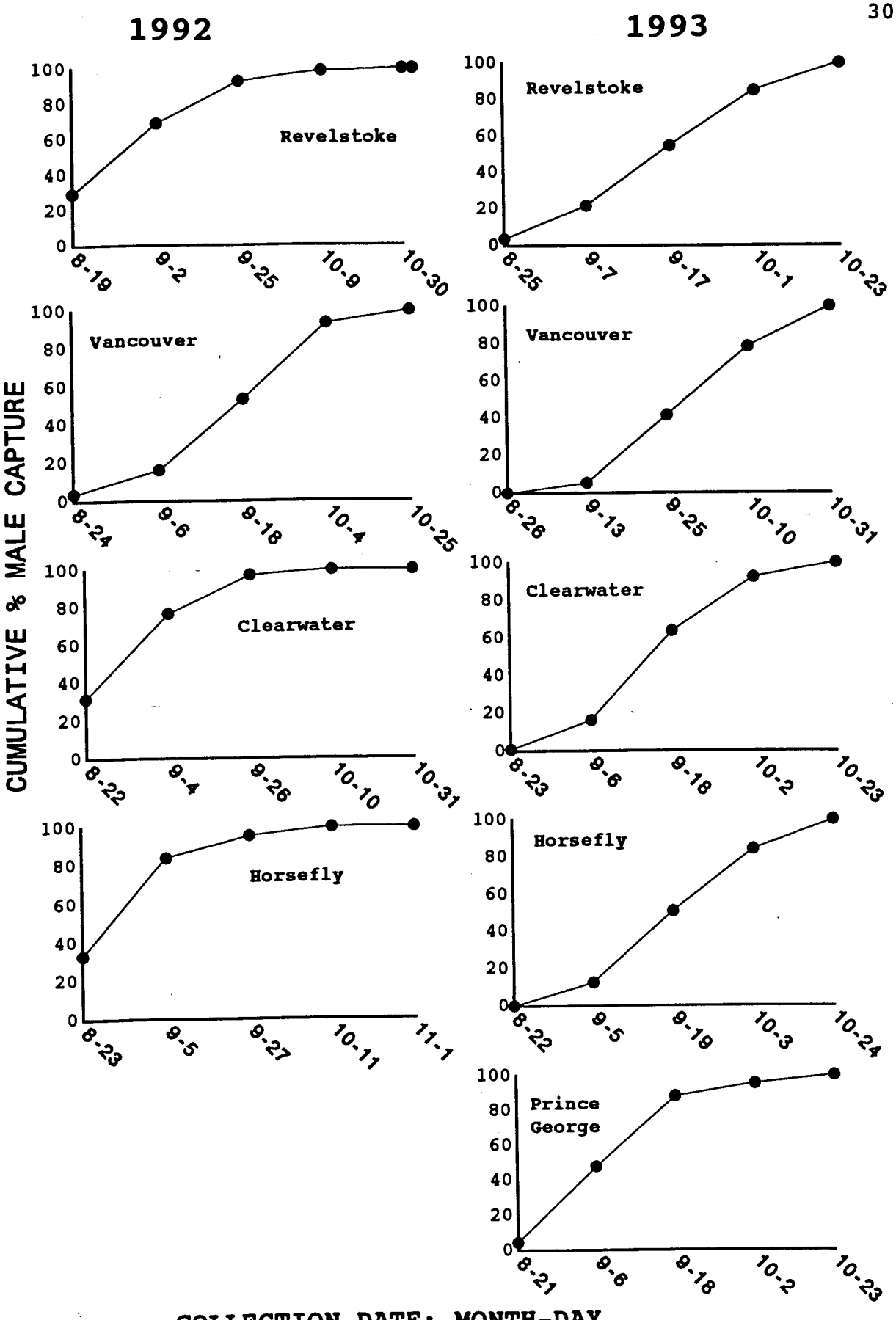

1992
1993
Revelstoke
Vancouver
Clearwater
Horsefly
Prince George
MEAN MALE MOTH CAPTURE PER DAY PER TRAPPING INTERVAL
MEAN DAILY TEMPERATURE (°C) AT 1300 h FOR EACH INTERVAL
Male moths
Temperature
COLLECTION DATE: MONTH-DAY

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


1992
1993
CUMULATIVE % MALE CAPTURE
Revelstoke
100
80
60
40
20
0
8-19
9-2
9-25
10-9
10-30
Revelstoke
8-25
9-7
9-17
10-1
10-23
Vancouver
8-24
9-6
9-18
10-4
10-25
Vancouver
8-26
9-13
9-25
10-10
10-31
Clearwater
8-22
9-4
9-26
10-10
10-31
Clearwater
8-23
9-6
9-18
10-2
10-23
Horsefly
8-23
9-5
9-27
10-11
11-1
Horsefly
8-22
9-5
9-19
10-3
10-24
Prince George
8-21
9-6
9-18
10-2
10-23
COLLECTION DATE: MONTH-DAY

2.2.2 *Dosage*

Male western hemlock loopers responded in a dose-dependent response to pheromone-baited traps in both 1992 and 1993 (Tables 2,3). In 1992, pheromone-baited traps attracted significantly more male moths than the unbaited traps in all regions and at all collection periods, with the exception of the Horsefly Region at collections 1 and 4 (Table 2). This is most likely because there were only 3 sites in this region and few moths flew prior to collection 1 (Fig. 1). At collection 4 analysis was not conducted due to many lost collections from this region.

In 1992 captures of males increased with pheromone-dose, but responses to the two highest doses (1000 µg and 10000 µg) were the same. An increase in capture of males with sex pheromone dose has been observed for the western hemlock looper (Gries *et al.* 1993) and for many other Lepidoptera (e.g. Baker *et al.* 1981; Turgeon *et al.* 1983; Sweeney and McLean 1990; Anshelevich *et al.* 1993). The fact that captures of male western hemlock loopers to the two highest doses did not differ significantly may support the threshold hypothesis described by Roelofs (1978). It is possible that some males were repelled or their flight was arrested in response to the highest pheromone dose of 10000 µg. This phenomenon was observed by Turgeon *et al.* (1983) who found that catches of male armyworms, *Pseudaletia unipuncta* (Haworth), increased in

Table 2. Mean numbers of male western hemlock loopers captured in pheromone-baited traps by dose and collection date, 1992

Area and number of replicates	Dose (µg)	Number of males (X̄±S.E.)[a] captured by collection date, month/day[b]				
		8/19-8/24	9/02-9/06	9/18-9/27	10/04-10/11	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	2733.3±478.5ab	1749.9±468.6b	1268.1±412.8b	197.6 ±76.9b
	1000	770.0 ±162.8a	4522.3±348.3a	4881.1±297.8a	3568.1±491.4a	760.2 ±122.0a
	10000	1538.1±564.3a	4997.8±443.3a	5610.0±239.2a	4039.0±527.1a	1431.5±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	1049.3±572.6b	408.0 ±257.4c	57.4 ±22.1c	2.71±1.61c
	100	1972.0±314.2ab	3342.7±714.9a	1155.1±252.2b	543.6 ±226.3b	24.6±10.6b
	1000	3476.0±278.9a	5525.1±365.1a	2617.3±627.2ab	1485.7±469.0a	90.3±28.4a
	10000	3342.7±512.9a	5321.8±546.6a	3675.8±853.5a	1472.0±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	1189.7±491.4b	269.0 ±115.2b		3.0 ±1.5bc
	100	1837.0±20.0a	3331.3±131.2a	1369.7±434.3a		6.0 ±4.6bc
	1000	1809.0a	5021.7±665.7a	2041.0±502.7a		33.0±15.6ab
	10000	1485.3±288.9a	4854.3±705.0a	3021.7±1157.4a		76.3±39.8 a
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 ±35.7bc	28.6±17.6b
	1000	11.1±5.9a	74.6±18.6a	221.5±68.9ab	279.5±83.5a	98.4±42.3a
	10000	13.1±4.8a	63.5±11.9a	187.3±33.7a	145.9±33.3ab	95.1±35.1a

[a] 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 $\log_e(x+1)$. Horsefly area collection 4, analyses not included due to many missing observations.
[b] Collections made at areas on different days bounded by time specified.

Table 3. Mean numbers of western hemlock loopers captured in pheromone-baited traps by dose and collection date, 1993

Region and number of replicates	Dose (µg)	Number of males ($\bar{X}$±S.E.)[a] captured by collection date, month/day[b]				
		8/21-8/26	9/05-9/13	9/17-9/25	10/01-10/10	10/22-10/31
Revelstoke	0	5.7 ±4.6c	9.1 ±3.5c	15.4 ±5.5c	9.4 ±3.7c	8.7 ±3.9c
n=9	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	1031.8±363.1a	933.7±359.7a	476.0±181.5a
Clearwater	0	0.3±0.3b	0.1 ±0.1b	1.3 ±1.3b	0.1±0.1c	0b
n=7	1	0.7±0.4ab	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	0	0a	0.7 ±0.5b	2.5 ±1.4c	1.0 ±0.7b	0.8 ±0.8c
n=6	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	0	0	0b	0c	0c	0b
n=7	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	0	13.6 ±5.5b	112.2 ±50.7b	107.4 ±62.7b	15.3 ±9.5b	9.8 ±6.7b
George	1	20.0 ±14.3b	143.0 ±7.9b	62.4 ±11.9b	13.8 ±2.0b	8.2 ±2.1b
n=5	10	151.4±30.7a	1403.4±550.3a	1303.0±786.0a	231.4±86.6a	153.6±79.5a

[a] 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 $\log_e(x+1)$.
[b] Collections made at areas on different days, bounded by time specified.

a dose-dependent manner, but a decrease in catch occurred at the highest dose of 3000 µg. It was suggested that an upper limit of responsiveness had been reached (Turgeon *et al.* 1983). Elkinton *et al.* (1987) found that for the gypsy moth, *Lymantria dispar* (L.), increasing synthetic sex pheromone emission rates in a forest environment resulted in responses of males from increasingly greater distances, but few of these males were able to orient to the source of the elevated pheromone source. Another possible explanation is that males were repelled from traps which contained a large number of dead insects. Sanders (1986) and Sweeney *et al.* (1990b) found that the presence of dead male eastern and western spruce budworms, respectively, in Unitraps reduced subsequent captures of males. Traps baited with 10000 µg lures caught large numbers of male western hemlock loopers, many of which were decomposing prior to collection. Elkinton (1987) showed that trap captures of male gypsy moths were further reduced in the presence of decomposed moths as compared to the presence of fresh or dry moths or a reduced head space from the insertion of a false bottom into a high-capacity trap.

Trap saturation could also explain why the same number of moths were attracted to both the 1000 and 10000 µg-baited traps. Even a high-capacity trap, such as a Unitrap, can become saturated when high pheromone concentrations are used at high population levels. The capture efficiency of a high capacity milk carton trap for gypsy moths was reduced when

false bottoms were inserted into the trap which resulted in a reduced head space available in the trap (Elkinton 1987). It is also possible that the presumably larger plume created by the 10000 µg lure was absorbed or reflected off various objects in the surrounding habitat and as a result fewer moths were attracted from a greater downwind distance. McNeil (1991) suggested that the spacing and size of different objects in the habitat surrounding the trap determines the degree to which the pheromone plume is deflected and dispersed. Discrimination among doses was most evident at the peak and latter half of the flight period in 1992 (Table 2).

In 1993, the 10 µg baited traps attracted significantly more moths than the unbaited control traps with the exception of the first collection period in Horsefly and Vancouver areas. In most instances the 1 µg-baited traps also caught significantly more moths than the control traps, but not in the Prince George or Horsefly areas where at all five and three out of five collection periods, respectively, the control trap and 1 µg-baited trap caught statistically the same number of males (Table 3). In the Prince George area no statistical difference was observed because control traps captured a large number of moths. Gries *et al.* (1993) found no difference in capture of male western hemlock loopers in previously used (100 µg) cleaned control traps and uncleaned control traps. However, despite assiduous cleaning of the traps between years, it is possible that the traps baited with

1000 and 10000 µg lures in 1992 were contaminated in 1993. Sanders (1992) found that evidence of trap contamination from one season to the next was most often a factor at high population levels of spruce budworm. At high populations 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 where populations were at outbreak levels in 1993.

In the Horsefly area, the lack of statistical difference between control and 1 µg-baited traps (Table 3) was probably because population levels were very low. This hypothesis is supported by the fact that control and 1 µg baited traps caught significantly different numbers of males at collection 3 which corresponded to the peak of the flight (Table 3).

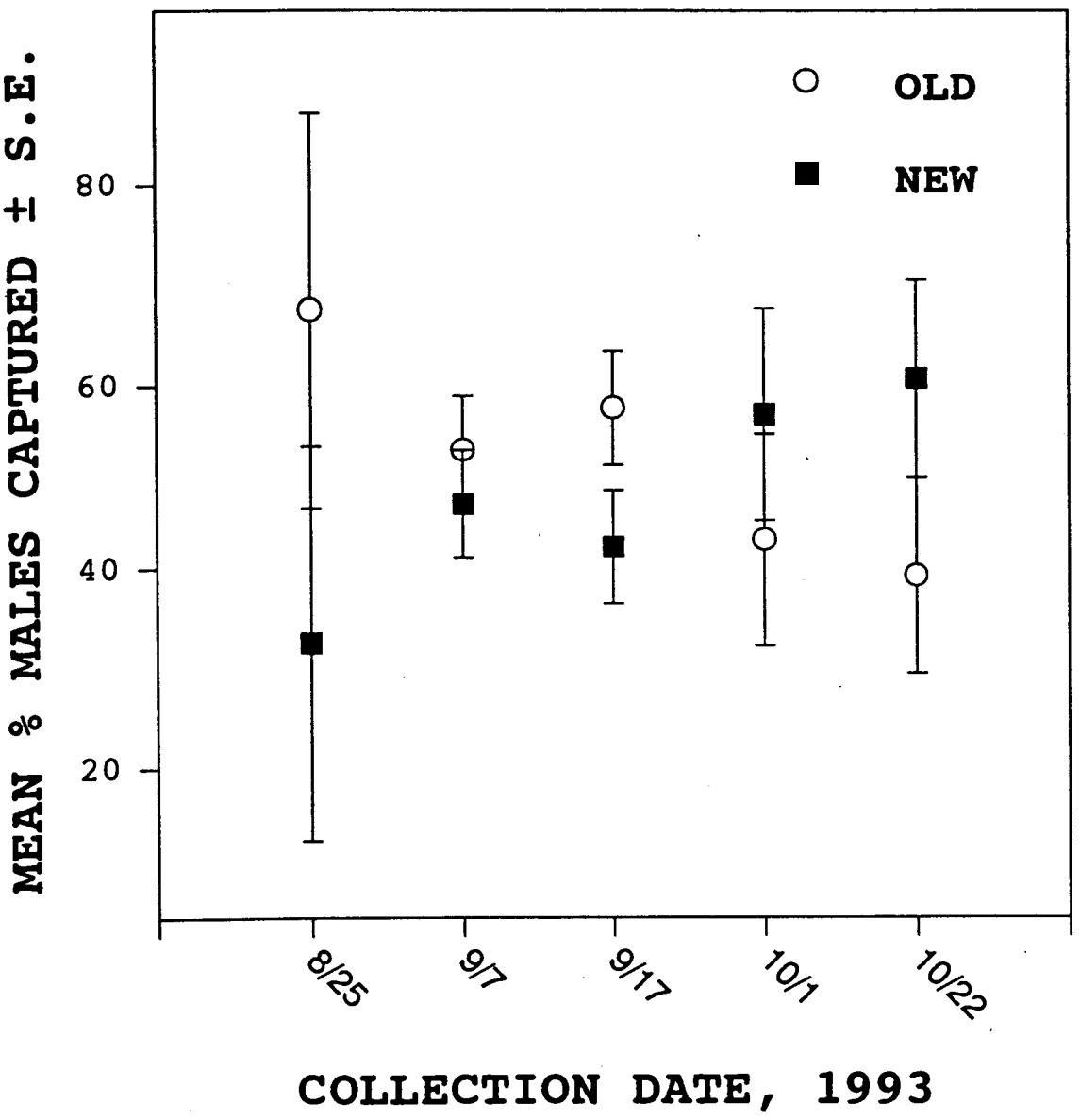
The consistency with which the 10 µg dose attracted significantly more moths than the 1 µg dose varied with region (Table 3). In the Revelstoke and Prince George areas the 10 µg-baited traps caught consistently more moths than the 1 µg-baited traps. In Horsefly and Vancouver areas the 10 µg-baited traps caught significantly more moths at all collections with the exception of the first collection, which is probably due to late emergence of moths in 1993 due to cool and wet summer conditions (Table 3). By contrast 10 µg-baited traps in the Clearwater area caught significantly more moths

than the 1 µg-baited traps only at the 4th collection period, probably because very few moths were flying in this region. Large variation among sites within the Clearwater area resulted in very large standard errors for trap catches in both 1 and 10 µg-baited traps (Table 3).

2.2.3 *Lure Longevity*

The intersecting mean percentages of male moths captured over time in Unitraps baited with freshly loaded and original 1 µg lures (Fig. 3) indicates a declining trend in the potency of the old lures over the flight season. However, this trend was not significant (r^2=0.0671, P=0.0756). The trend might have been more apparent if a larger sample size had been used in the experiment. A declining trend was not observed for the 10 µg lures (r^2=0.0710, P=0.0667) indicating no significant decline in potency over the entire flight period. Septa containing different doses of pheromone will exhibit different release rates (Daterman 1982). The release rate of compounds from rubber septa is based on first order kinetics, meaning that the release rate of a compound is dependent on the amount of material remaining in the device (Weatherston 1989). Properties of the active ingredient, including molecular weight and chemical functionality, also affect release rate (Daterman 1982). Hydrocarbons, such as the two components used to trap male western hemlock loopers, are chemically less reactive than organic compounds with polar functional groups

Fig. 3. Mean percentage of total male western hemlock loopers captured in traps freshly baited (25 August, 7 September, 17 September, 10 October) with 1 μg pheromone lures, compared with mean percentage in traps containing the original 1 μg lures throughout the flight season, 1993.


MEAN % MALES CAPTURED ± S.E.
80
60
40
20
OLD
NEW
8/25
9/7
9/17
10/1
10/22
COLLECTION DATE, 1993

(Fessenden and Fessenden 1986). This may partially explain the enduring potency of both the 1 and 10 µg lures throughout the three-month (August through October) trapping period. Another explanation is the relatively cool summer temperatures in 1993 (Fig. 1), that probably mediated release rates (Daterman 1982). A gradual decline in the attractiveness of traps baited with rubber septa containing a 2 mg dose of the sex pheromone components, (*Z*)-11-hexadecenal and (*Z*)-13-octadecenal of the honey dew moth, *Cryptoblabes gnidiella* (Mill.), resulted in the necessity to change lures at 2-3 week intervals (Anshelevich *et al.* 1993). The decline in attractiveness of these compounds is probably due to a combination of rapid degradation of the aldehyde components and high field temperatures in Israel. Age of baited lures has been shown to be an important factor in the attractiveness of pheromone-baited traps in several other systems (e.g. Hoyt *et al.* 1983; Sanders and Meighen 1987; Sweeney *et al.* 1990b; Jansson *et al.* 1992). In a monitoring system for the western hemlock looper, 1 µg lures show a slight trend to decreased potency at the end of the season but 10 µg lures have sufficient potency for an entire flight season.

2.2.4 *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 only in the 10 µg-baited traps (Table 4). However, 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 cm^2 sticky surface occurred when as few as 100 moths were captured, possibly because in some traps moths were captured only on the outer edge near the entrance of the trap. The efficiency of sticky traps decreases as the sticky surface becomes occupied with moths (Houseweart *et al.* 1981; Ramaswamy and Cardé 1982; Sanders 1986; Polavarapu and Seabrook 1992). Saturation with non-target diptera occurred on two occasions in baited traps in the Prince George area. The capture of non-target insects and general debris often reduces the effectiveness of sticky traps (Ramaswamy and Cardé 1982). Despite considerable care, contact between the lures and the adhesive, in several instances, could have affected the release rate of the pheromone. However, McNally and Barnes (1981) found that placement of septa in the sticky adhesive of traps did not affect captures of male codling moths, *Cydia pomonella* (L.), over a nine week period. In general, sticky traps were much more difficult and time consuming to handle, than the Unitraps.

Table 4. Comparison of captures of male western hemlock loopers in similarly baited sticky traps and Unitraps.

Dates	Dose (µg)	Number of sites	Trap type	Numbers of males captured ($\bar{x}$±S.E.)	*P* between trap type, Wilcoxon Rank Sum Test
7-25 Aug., 1993	0	18	sticky	0.6±0.3	0.0469
			Unitrap	6.1±2.8	
	1	16	sticky	8.2±3.0	0.1580
			Unitrap	17.7±8.6	
	10	20	sticky	20.1±4.5	0.0154
			Unitrap	85.3±25.7	
17 Sept.-1 Oct., 1993	0	6	sticky	2.8±1.3	0.1875
			Unitrap	12.0±4.5	
	1	7	sticky	12.0±3.4	0.0156
			Unitrap	117.0±37.6	
	10	7	sticky	68.1±12.5	0.0156
			Unitrap	346.9±121.3	

Operational difficulties that may occur with the use of Unitraps in a monitoring system for the western hemlock looper include: repellency of moths due to the accumulation of dead insects or the killing agent used in the trap (Sanders 1986, 1992); contamination from previous pheromone use (Sanders 1992), but not at pheromone loads of less than or equal to 100 µg (Gries *et al.* 1993); labour involved in trap washing, and space for trap storage (Sanders 1992).

Although operational difficulties can be experienced with either type of trap, the most appropriate trap to meet the goal of the monitoring system should be used. Trap saturation is not a problem when the aim is to detect populations or to monitor low populations. If quantitative estimates of the population are required, particularly at moderate to high levels (Houseweart *et al.* 1981; Polavarapu and Seabrook 1992), as is the case for the western hemlock looper, then trap saturation is an important problem. Comparison of the two trap types indicates that sticky traps are easily saturated and would not be appropriate for monitoring moderate to high level populations of the western hemlock looper.

3.0 MONITORING OF WESTERN HEMLOCK LOOPER WITH PHEROMONE-BAITED TRAPS

One of the potential uses of a monitoring system employing pheromone-baited traps is the quantitative prediction of population densities (Sanders 1988).

There are two main methods of determining the relationship between numbers of insects captured in traps and population density: 1) correlation between numbers of captured insects and sampled numbers of other stages of the insect population (Sanders 1988); and 2) mark-release-recapture experiments (Elkinton and Cardé 1980; Ramaswamy *et al.* 1983).

In many instances predictive monitoring of insect pest populations requires sampling immature stages (Thistlewood and McMullen 1989; McBrien *et al.* 1994). Many of these techniques are costly and labour intensive (Sanders 1988; Shore 1990). By correlating population densities determined from samples of immature stages with numbers of insects captured in pheromone-baited traps a predictive tool may be developed which is less costly or less labour intensive than other sampling methods. Assuming that pheromone-baited traps provide an accurate assessment of adult populations (which is not necessarily the case), the success of these types of correlations will depend on the accuracy of the sample technique for the immature stages (Sanders 1988).

A validated pheromone-based sampling system has been developed for the eastern spruce budworm (Ramaswamy *et al.* 1983; Allen *et al.* 1986; Sanders 1988). Ramaswamy *et al.* (1983) showed that larval populations and numbers of male budworms captured in pheromone-baited traps were highly correlated within the same generation. Sanders (1988) found that numbers of males captured in pheromone-baited traps were correlated with larval populations within the same generation (r^2=66%) and in the subsequent generation (r^2=81%). This finding, incorporated with yearly trap catch information for twenty-one consecutive years led to the development of a tool that can alert forest managers six years in advance of extensive defoliation (Sanders 1988). Other insects for which a quantitative relationship between pheromone trap catch and samples of immature stages has been demonstrated include : the gypsy moth, *Lymantria dispar* (L.) (Granett 1974); the potato tuberworm, *Phthorimaea operculella* (Zeller)(Shelton and Wyman 1979); the Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough)(Daterman 1980; Shepherd *et al.* 1985); the tobacco budworm, *Heliothis virescens* (F.)(Tingle and Mitchell 1981); the orange tortrix, *Argyrotaenia citrana* (Fernald)(Knight and Croft 1987); the mullein bug, *Campylomma verbasci* (Meyer)(Smith and Borden 1990; McBrien *et al.* 1994); the western spruce budworm, *Choristoneura occidentalis* (Freeman) (Sweeney *et al.* 1990b); the pickleworm, *Diaphania nitidalis* (Stoll)(Elsey *et al.* 1991); the blueberry leaftier, *Croesia curvalana* (Kearfoot)(Polavarapu and Seabrook 1992); and

Argyrotaenia pulchellana (Haw.) (Faccioli *et al.* 1993).

The accuracy of pheromone-baited trap catches as estimates of population densities can also be validated through mark-release-recapture experiments, assuming that the proportions of wild and released males captured are comparable (Ramaswamy *et al.* 1983). Elkinton and Cardé (1980) used a technique of uniform and point releases of marked male gypsy moths to estimate population density depicted by pheromone-baited traps and distance of dispersal. They found that uniform releases estimated population density, but that point releases estimated only maximum population density. Similarly, Ramaswamy *et al.* (1983) tentatively estimated population density of the spruce budworm based on mark-release-recapture of both wild and laboratory-reared males.

The development of a predictive system which can warn the forest manager of impending outbreaks of the western hemlock looper would be of considerable practical use, as populations of this insect erupt suddenly into outbreak proportions (Harris *et al.* 1982). Therefore, my objective was to evaluate the ability of pheromone-baited traps to estimate population density of the western hemlock looper by comparing numbers of males captured in pheromone-baited traps to numbers of larvae, pupae and eggs sampled by other methods.

3.1 METHODS AND MATERIALS

To determine if male moth catches in pheromone-baited traps were accurate measures of population density, and could be predictive of populations in subsequent generations, counts of captured males were compared to sampled numbers of immature stages of the western hemlock looper in the same and subsequent generations. Male moth counts were obtained from Unitraps, prepared and placed in the field as described previously.

3.1.1 *Sampling of Immature Stages*

Larvae were sampled using the FIDS three-tree beating method. A 2.75 m pole was used to dislodge larvae from a western hemlock tree onto a 2 by 3 m sheet. Trees that could be reached on the edge of the forest were sampled. All the foliage was sampled on small trees and foliage in the lower crown on all sides of the tree was sampled on larger trees. Three trees were sampled at each site. I sampled the sites in the Vancouver area in both 1992 and 1993 and in the Clearwater area in 1992; all other samples were taken by FIDS rangers.

Pupal traps were placed on three western hemlock trees on July 10-20, 1992 and June 21-27, 1993. Traps consisted of burlap strips (Northwest Sack Company, Vancouver, B.C.), 0.50 m wide, wrapped around the tree two times at breast

height (1.3 m) and secured with staples. The diameter at breast height of the sample trees ranged from 80 to 250 cm. A spruce tree was sampled at one site in the Prince George area as most of the western hemlock trees were dead. Pupal traps remained on the trees for the entire pupation period (10-20 July - 19-24 August, 1992 and 21-27 June - 21-26 August, 1993). Traps were dismantled in mid-August in both years, rolled up and placed individually into paper bags and secured with staples for transport to the laboratory. Pupae that were on the bark, underneath the trap were removed with forceps and placed in the paper bags. Pupae were stored at 4°C until they were counted. All pupae including an unknown number of parasitized pupae were used in analyses.

In all instances lichen samples (*Alectoria spp.*) for making egg counts were collected from western hemlock trees by FIDS rangers. Eggs were removed from the lichen using the hot water extraction method (Shore 1990), and recorded as number of eggs per 100 g of lichen. Egg parasitism, based on egg coloration, and the ratio of new:old eggs are also determined at this time (C.S. Wood[2], pers. comm.). In 1992, 11 sites were sampled for egg masses and in 1993, 23 sites were sampled.

---

[2]Head Ranger, Canadian Forest Service-Pacific and Yukon Region, Pacific Forestry Centre, Victoria, B.C..

3.1.2 *Comparison of Numbers of Captured Males and Numbers of Immature Stages*

In 1992 and 1993 larval and pupal counts were regressed against numbers of males captured in pheromone-baited traps (dependent variable). In 1992, numbers of males and larvae were transformed by $\log_e(x+1)$ and numbers of pupae by $\sqrt{x}$ to adjust for non-normal sample distributions (Zar 1984). In 1993, all three variables were transformed by $\log_e(x+1)$ to correct for non-normal distributions (Zar 1984).

In 1992, numbers of captured males at each dose were regressed against egg counts of the subsequent generation. Both variables were tested for normality and numbers of male moth catches were transformed by $\sqrt{x}$ (Zar 1984). The normality of the egg sample distribution was not improved by either $\log_e(x+1)$ or $\sqrt{x}$ transformations, and therefore remained untransformed. A larger than expected number of eggs occurred at one site in the Revelstoke area, possibly due to the immigration of moths from outside the trapping area. This outlier was justifiably omitted from the regression analysis (SAS Institute Inc. 1988). In 1993, numbers of captured males were again regressed against egg counts of the subsequent generation. After testing each sample distribution for normality both variables were transformed by $\log_e(x+1)$ (SAS Institute Inc. 1988). Omission of the outlier site in the Revelstoke area was again statistically justified (SAS

Institute Inc. 1988).

The predictive capability of male moth catches in determining subsequent larval and pupal populations was determined by regressing numbers of captured males from 1992 with larvae and pupae in 1993. Larval and pupal numbers were both transformed by $\log_e(x+1)$ to correct for non-normal distributions prior to analysis (Zar 1984).

3.2 RESULTS AND DISCUSSION

3.2.1 *Same-Generation Relationships*

Numbers of male western hemlock loopers captured in pheromone-baited traps were related to numbers of sampled larvae and pupae within the same generation (Table 5). Similar same generation relationships between samples of immature stages and catches of adult males in pheromone-baited traps have been shown in several instances (Granett 1974; Shelton and Wymann 1979; Tingle and Mitchell 1981; Ramaswamy *et al.* 1983; Allen *et al.* 1986; Sanders 1988; Knight and Hull 1988;). In 1992, the relationship between the numbers of captured males and the numbers of larvae sampled was strong at the first collection, increased in strength until the third collection, decreased at the fourth collection and became non-significant at the fifth collection (Table 5). The relationship between captured males and pupae was strong at the first collection but decreased progressively over the flight period and was non-significant at the fourth and fifth collections. When the total of all male moths captured was compared to larval and pupal samples in 1992, strong relationships were seen in both instances (Table 5).

In 1993, the relationship between numbers of captured males and larvae was strong at the first collection and steadily decreased in strength until it became non-significant

Table 5. Relationship between male moths captured in 10 µg-baited traps and larvae and pupae in the same generation.

Year	Collection date month/day[a]	Indep't var.	Regression equation	r^2	*P*
1992	8/19-8/24	larvae	$\log_e(y+1)=2.20+1.12[\log_e(x+1)]$	0.5362	0.0001
		pupae	$\log_e(y+1)=2.44+0.19\sqrt{x}$	0.5606	0.0001
	9/02-9/06	larvae	$\log_e(y+1)=2.93+1.15[\log_e(x+1)]$	0.5519	0.0001
		pupae	$\log_e(y+1)=3.26+0.18\sqrt{x}$	0.5572	0.0001
	9/18-9/27	larvae	$\log_e(y+1)=2.98+0.82[\log_e(x+1)]$	0.6464	0.0001
		pupae	$\log_e(y+1)=3.66+0.09\sqrt{x}$	0.3590	0.0012
	10/04-10/11	larvae	$\log_e(y+1)=3.07+0.39[\log_e(x+1)]$	0.3002	0.0027
		pupae	$\log_e(y+1)=3.51+0.03\sqrt{x}$	0.0391	0.1780
	10/25-11/01	larvae	$\log_e(y+1)=1.51+0.11[\log_e(x+1)]$	-0.0176	0.4586
		pupae	$\log_e(y+1)=1.70-0.002\sqrt{x}$	-0.0449	0.9131
	Total	larvae	$\log_e(y+1)=4.63+0.85[\log_e(x+1)]$	0.6484	0.0001
		pupae	$\log_e(y+1)=4.98+0.13\sqrt{x}$	0.5681	0.0001
1993	8/21-8/26	larvae	$\log_e(y+1)=-0.04+1.17[\log_e(x+1)]$	0.6436	0.0001
		pupae	$\log_e(y+1)= 0.18+0.97[\log_e(x+1)]$	0.7979	0.0001
	9/05-9/13	larvae	$\log_e(y+1)=2.43+1.04[\log_e(x+1)]$	0.5459	0.0001
		pupae	$\log_e(y+1)= 2.64+0.87[\log_e(x+1)]$	0.6676	0.0001
	9/17-9/25	larvae	$\log_e(y+1)= 4.23+0.58[\log_e(x+1)]$	0.3072	0.0009
		pupae	$\log_e(y+1)= 4.23+0.56[\log_e(x+1)]$	0.5486	0.0001
	10/01-10/10	larvae	$\log_e(y+1)= 4.31+0.32[\log_e(x+1)]$	0.0847	0.0652
		pupae	$\log_e(y+1)= 4.12+0.41[\log_e(x+1)]$	0.3082	0.0006
	10/22-10/31	larvae	$\log_e(y+1)= 3.09+0.41[\log_e(x+1)]$	0.0788	0.0726
		pupae	$\log_e(y+1)= 3.07+0.43[\log_e(x+1)]$	0.2065	0.0052
	Total	larvae	$\log_e(y+1)= 5.17+0.64[\log_e(x+1)]$	0.3766	0.0002
		pupae	$\log_e(y+1)= 5.14+0.61[\log_e(x+1)]$	0.6064	0.0001

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

at the fourth and fifth collections (Table 5). The relationship between captured males and pupae was strong initially and decreased over the flight period but was significant throughout the flight (Table 5). When total numbers of males were related to numbers of larvae and pupae sampled in 1993 the larval/moth relationship was much weaker than the pupal/moth relationship (Table 5). This may be due to the influence of cool, wet and variable weather on larval samples obtained from the three-tree beating method (Harris *et al.* 1972).

The declining significance of the relationships between immature stages and adult males as the season progressed, in both 1992 and 1993, suggests that the majority of males fly during the first half of the flight and the numbers of late-emerging males are not representative of the entire population. Other factors that may contribute to variation observed in these models include: immigration of males (Granett 1974); inclusion of parasitised pupae in the analyses; and differences in pheromone trap capture among plots due to environmental factors such as local weather conditions, topography and stand composition (Sanders 1988). The relationship between spruce budworm larvae and males trapped in pheromone-baited traps was strengthened when data were split by region alleviating some of the variability of local environmental factors (Allen *et al.* 1986).

Finally, samples of immatures can only be representative of a portion of the population. Young western hemlock looper larvae tend to feed at the tops of trees and older larvae migrate down the tree to feed in the lower crown (Erickson 1984) where they can be readily sampled using the three-tree beating method. Further bias may have occurred because only western hemlock trees were sampled. Although western hemlock is the preferred host of the western hemlock looper (Erickson 1984), in severely defoliated sites larvae may have moved to other food sources. Allen *et al.* (1986) found that spruce budworm larval populations on different hosts showed different correlations with numbers of males captured in pheromone-baited traps and suggested that larvae should be sampled from both balsam fir and spruce trees. Collection efficiency could also influence sampling accuracy, as burlap traps captured only 20% of the eastern hemlock looper pupae on a sampled tree (Otvos 1974).

Sampling for larvae and pupae gives a tree-specific estimate of population density, whereas catches in pheromone-baited traps give an area-wide estimate. A weighting factor of host-plant foliage was used to adjust for the disparity in sample area between variables when comparing larvae of the eastern spruce budworm with catches of males in pheromone-baited traps (Sanders 1988). In this case the r^2 values were not increased (Sanders 1988) but Sweeney *et al.* (1990b) found that dividing the male western spruce budworm catch by either

basal area or foliage biomass per hectare in each plot resulted in significant correlations with larval density in the following generation. Such a weighting factor could significantly increase correlations between immatures and adults sampled by different methods. The relatively strong relationships between numbers of immature and adult western hemlock loopers in the same generation (Table 5) provide a measure of confidence in predicting the potential size of the population in the next generation.

3.2.2 *Between-Generation Relationships*

Male western hemlock looper catches in 10 µg pheromone-baited traps were predictive of egg counts in the subsequent generation (Figs. 4,5), indicating that male moth catches can be used to predict the size of the subsequent generation. In 1992 numbers of captured males predicted subsequent egg counts at collections 1-3 (Fig. 4), encompassing the peak flight in all areas (Fig. 1). In collections 4 and 5 the predictive capability of the male moth captures was lost. The predictive capability of the total number of males captured was as strong as at the first collection period. These findings suggest that monitoring should be done during the first half of the flight season or for the entire season.

In 1993 intensified egg sampling supported the 1992 findings. The relationship between numbers of captured males

Fig. 4. Relationship between numbers of male western hemlock loopers captured in 10 µg-baited traps and egg counts in the subsequent generation by collection date in 1992.

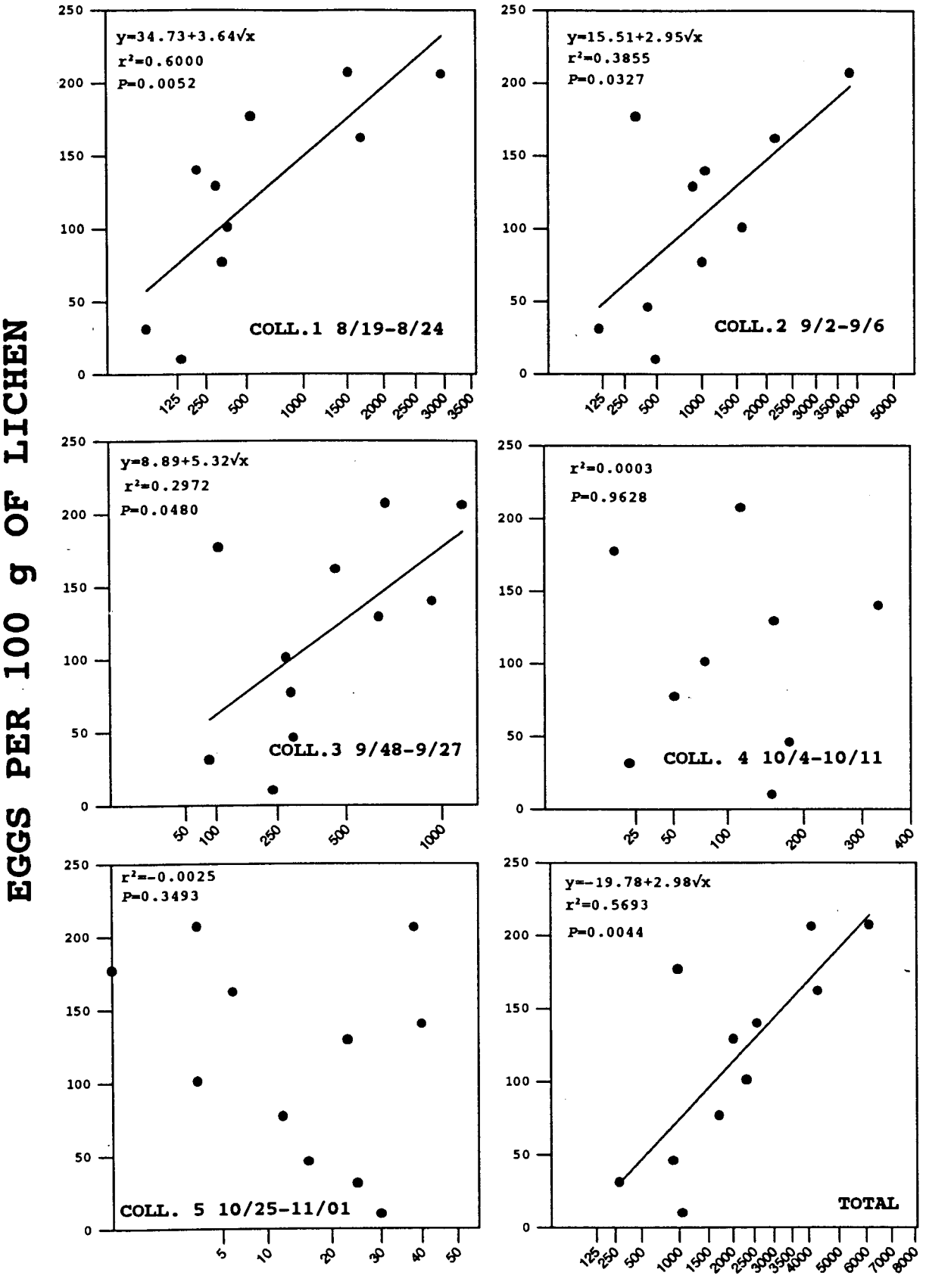
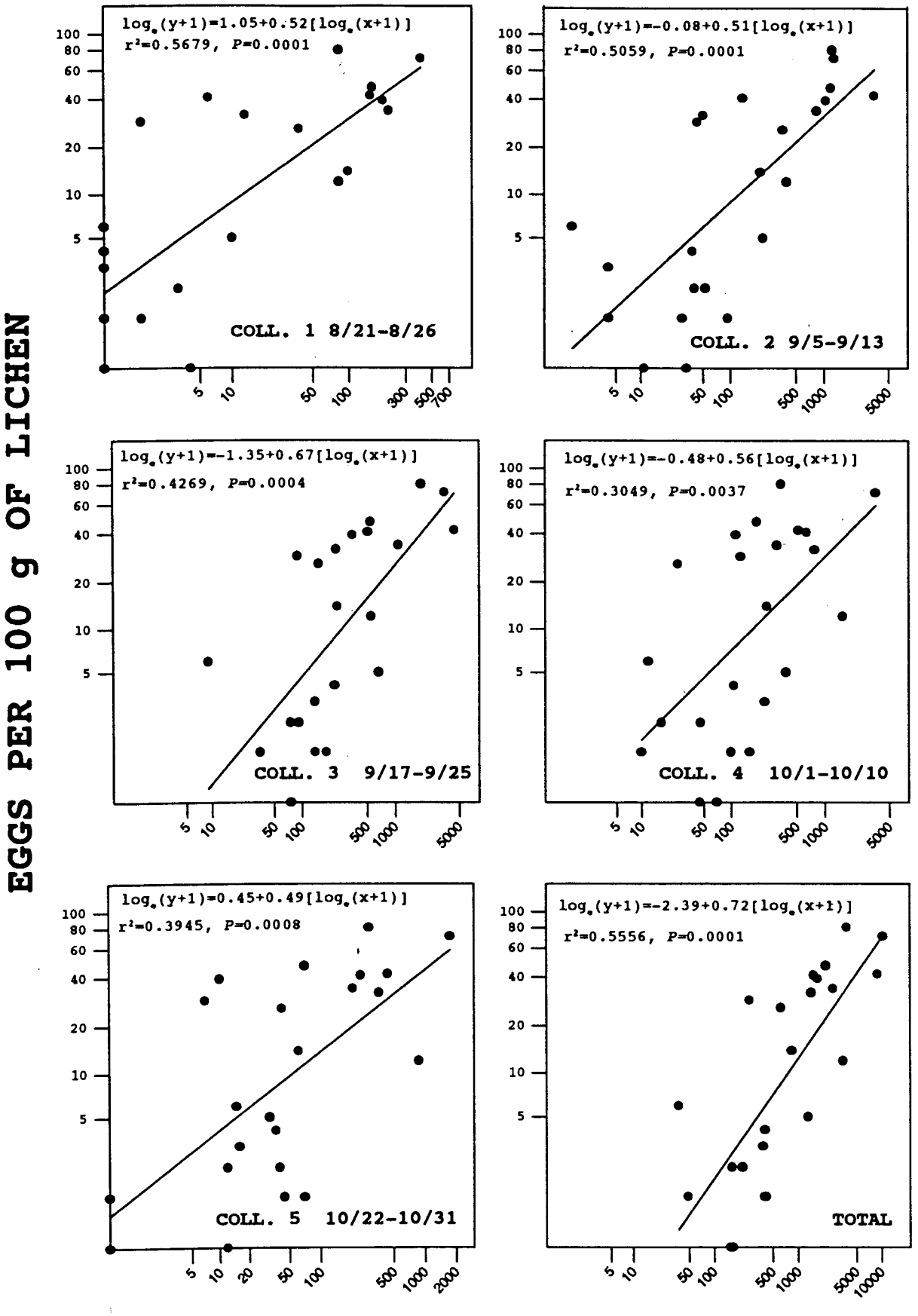

y=34.73+3.64√x
r²=0.6000
P=0.0052
COLL.1 8/19-8/24
y=15.51+2.95√x
r²=0.3855
P=0.0327
COLL.2 9/2-9/6
y=8.89+5.32√x
r²=0.2972
P=0.0480
COLL.3 9/48-9/27
r²=0.0003
P=0.9628
COLL. 4 10/4-10/11
r²=-0.0025
P=0.3493
COLL. 5 10/25-11/01
y=-19.78+2.98√x
r²=0.5693
P=0.0044
TOTAL
EGGS PER 100 g OF LICHEN
NUMBER OF MALES CAPTURED

Fig. 5. Relationship between numbers of male western hemlock loopers captured in 10 μg-baited traps and egg counts in the subsequent generation by collection date in 1993.


log$_e$(y+1)=1.05+0.52[log$_e$(x+1)]
r²=0.5679, P=0.0001
COLL. 1 8/21-8/26
log$_e$(y+1)=-0.08+0.51[log$_e$(x+1)]
r²=0.5059, P=0.0001
COLL. 2 9/5-9/13
log$_e$(y+1)=-1.35+0.67[log$_e$(x+1)]
r²=0.4269, P=0.0004
COLL. 3 9/17-9/25
log$_e$(y+1)=-0.48+0.56[log$_e$(x+1)]
r²=0.3049, P=0.0037
COLL. 4 10/1-10/10
log$_e$(y+1)=0.45+0.49[log$_e$(x+1)]
r²=0.3945, P=0.0008
COLL. 5 10/22-10/31
log$_e$(y+1)=-2.39+0.72[log$_e$(x+1)]
r²=0.5556, P=0.0001
TOTAL
EGGS PER 100 g OF LICHEN
NUMBER OF MALES CAPTURED

and numbers of eggs in the next generation was always significant, being strong in the initial two collections, gradually decreasing until the fourth collection, then increasing again slightly at the fifth and final collection (Fig. 5). As in 1992 the numbers of males captured in the first collection and the total numbers captured in 10 µg-baited traps over the entire flight period were equally good predictors of eggs in the subsequent generation.

Capture of male moths in the first three collection periods combined was also predictive of eggs in the subsequent generation in both 1992 (r^2=0.5971, P=0.0032, $y=-14.00+2.95\sqrt{x}$) and 1993(r^2=0.5067, P=0.0001, $\log_e(y+1)=-1.55+0.65[\log_e(x+1)]$). From a management perspective the predictive capability of collections 1-3 combined is of practical importance as traps would probably be maintained in the field over this period.

The superiority of catches at the beginning of the flight period in predicting subsequent egg populations suggests that most mating and oviposition occurs in the first half of the flight period when the majority of the males have usually emerged (Fig. 2). A male-biased sex ratio was found to be most favourable for mating success of the western hemlock looper (Ostaff *et al.* 1974b). Western hemlock looper males are protandrous, eclosing before females (Hopping 1934), and sweep net samples throughout the first half of the flight season indicated that the male : female ratio decreased over

the first half of the flight season (Ostaff *et al.* 1974a). Males were attracted to traps baited with virgin females only during the first half of the season, and Ostaff *et al.* (1974a) suggested that competition from feral females in the second half of the flight inhibited trap catch, which infers a decrease in the male:female ratio and perhaps less mating success as the season progresses. The observation made by Dewey *et al.* (1972) that western hemlock loopers in Oregon fly until November but most oviposition occurs from mid-September to mid-October, also supports the hypothesis that most mating and oviposition occurs in British Columbia in the first half of the flight period.

Further research needs to be conducted in order to determine how long adults live in the field and their mating status and emergence patterns throughout the flight season before conclusions can be drawn regarding the peak period of mating and oviposition. West and Bowers (1994) showed that temperature affected the calling behavior of female eastern hemlock loopers and suggested that this was adaptive for calling at low temperatures at the end of the flight season. If females are capable of calling throughout the flight season presumably mating and oviposition will also continue until the end of the season.

Light trapping studies throughout the flight period could determine emergence patterns and sex ratio of western hemlock

looper adults. The mating status of males captured in pheromone-baited traps could also be determined, presuming that mated males are captured at a similar frequency as virgins. The presence of a dark coloured fluid in the primary simplex can distinguish virgin male spruce budworms from mated males captured in pheromone-baited traps (Bergh and Seabrook 1986a). A low frequency of mated male western hemlock loopers captured would be expected at the beginning of the flight period if the western hemlock looper is protandrous (Bergh and Seabrook 1986b). The frequency of mated males should increase up to the peak flight and should decrease thereafter if most mating occurs in the first half of the flight period. In a similar study, Bergh and Seabrook (1986b) showed that mated male spruce budworms were captured in small proportions at the beginning and end of the flight season. It was suggested that either pheromone-baited traps selectively captured virgin males or regeneration of the pigment in the ejaculatory fluid of mated males resulted in a misreading of male status (Bergh and Seabrook 1986b). If virgin male western hemlock loopers were selectively captured in pheromone-baited traps this factor alone could explain the poor predictive capability of male captures in the latter half of the flight.

It is also possible that females discriminate against unsuitable (small) mates as found in tobacco moths, *Ephestia elutella* (Hübner) (Phelan and Baker 1986). Western hemlock looper males appeared to decrease in size at the end of the

flight (personal observation), which may have resulted in lowering their mating potential.

The decreasing pattern of association between male moths and subsequent egg populations (Fig. 4,5), could also be due to preferential oviposition in the first half of the flight on *Alectoria spp.* of lichen, as compared to other unsampled substrates. Although different oviposition sites do occur (Kinghorn 1952; Thomson 1958; Carolin *et al.* 1964) and preference for lichen over moss occurs in interior forests (Shore 1990), there is no documentation of changing preference of oviposition sites over time for western hemlock loopers. It is possible that other semiochemicals are involved in the placement of western hemlock looper eggs. West and Bowers (1994) observed marking behavior by female eastern hemlock looper virgin and mated females and suggested that this activity may be associated with other activities besides mate attraction, such as oviposition. If oviposition deterrents are given off by female western hemlock loopers, which cause conspecific females to disperse before oviposition, this could also explain the poor relationships between males captured at the end of the season and subsequent egg counts.

Numbers of males captured in traps baited with 1, 100, 1000 and 10000 μg doses were not as successful as those in traps baited with the 10 μg dose in predicting subsequent egg samples (Table 6; Fig. 4,5). This is most likely because

Table 6. Relationship between numbers of male western hemlock loopers captured in pheromone-baited traps and eggs in the next generation, by collection and dose, 1992 and 1993.

Year	Collection date month/day[a]	Dose (μg)	Regression equation	r^2	*P*
1992	8/19-8/24	100	$y=11.46+3.51\sqrt{x}$	0.4563	0.0135
		1000	$y=12.78+2.96\sqrt{x}$	0.3895	0.0318
		10000	$y=29.54+2.33\sqrt{x}$	0.2784	0.0550
	9/02-9/06	100	$y=-71.22+3.52\sqrt{x}$	0.4923	0.0097
		1000	$y=-128.01+3.54\sqrt{x}$	0.1281	0.1506
		10	$y=-167.93+3.98\sqrt{x}$	0.3423	0.0344
	9/18-9/27	100	$y=84.07+0.85\sqrt{x}$	-0.0746	0.5939
		1000	$y=319.72-3.18\sqrt{x}$	0.1761	0.1103
		10000	$y=-361.62+6.48\sqrt{x}$	0.0068	0.3329
	10/04-10/11	100	$y=132.28-0.65\sqrt{x}$	-0.1010	0.6871
		1000	$y=213.72-1.84\sqrt{x}$	0.0768	0.2089
		10000	$y=170.71-0.86\sqrt{x}$	-0.0976	0.6669
	10/25-11/01	100	$y=155.77-2.91\sqrt{x}$	-0.0070	0.3613
		1000	$y=173.41-2.58\sqrt{x}$	0.0858	0.1973
		10000	$y=148.52-0.83\sqrt{x}$	-0.0635	0.5155
	Total	100	$y=-12.10+1.59\sqrt{x}$	0.1876	0.1022
		1000	$y=133.01-0.14\sqrt{x}$	-0.1104	0.9399
		10000	$y=-265.51+3.01\sqrt{x}$	0.2264	0.0789
1993	8/21-8/26	1	$\log_e(y+1)=1.43+0.67[\log_e(x+1)]$	0.4172	0.0005
	9/05-9/13	1	$\log_e(y+1)=0.35+0.64[\log_e(x+1)]$	0.5536	0.0001
	9/17-9/25	1	$\log_e(y+1)=0.19+0.62[\log_e(x+1)]$	0.3209	0.0029
	10/1-10/10	1	$\log_e(y+1)=0.90+0.53[\log_e(x+1)]$	0.2004	0.0186
	10/22-10/31	1	$\log_e(y+1)=1.24+0.56[\log_e(x+1)]$	0.2493	0.0089
	Total	1	$\log_e(y+1)=-1.37+0.81[\log_e(x+1)]$	0.5297	0.0001

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

stronger lures (100-10000 µg) attracted males over a longer distance, increasing the disparity of the area sampled by the two methods. Daterman (1980) found that numbers of male Douglas-fir tussock moths captured in pheromone-baited traps best predicted the subsequent larval population when very low concentrations of pheromone, corresponding to 3000-30000 times less potent than the virgin female, were used. Predictions using the captured males in 1 µg-baited traps, with the exception of collection 2, were not as accurate as predictions using the 10 µg-baited trap captures. This could be due to the absorption and deflection of the plume (McNeil 1991) making it less attractive to males. It is also possible that under field conditions diffusion of volatiles from 1 µg lures results in concentrations approaching the lower threshold of responsiveness of the male moth, or that at this low dose, traps are out-competed by wild females.

Table 7 shows that the numbers of males captured in 1992 failed to predict larval and pupal numbers in 1993. Egg parasitism, and various other mortality factors, probably account for most of the poor relationships. Substantial egg parasitism is often recorded by FIDS, and when greater than 30% parasitism occurs, a collapse of an outbreak population is imminent (Koot and Hodge 1992). If a weighting factor of % egg parasitism had been incorporated into the model, a better prediction may have resulted. This could have been particularly successful in the Horsefly and Clearwater Regions

Table 7. Relationship between numbers of male western hemlock loopers captured in 10 µg-baited traps and larvae and pupae in the next generation.

Collection date month/day[a] (1992)	Dependent Variable (1993)	Regression Equation	r^2	*P*
8/19-8/24	larvae	$\log_e(y+1)= 1.21+0.0002x$	-0.0157	0.4304
	pupae	$\log_e(y+1)= 1.06+0.0004x$	-0.0162	0.4349
9/02-9/06	larvae	$\log_e(y+1)= 1.27+0.0002x$	-0.0143	0.4158
	pupae	$\log_e(y+1)= 1.16+0.0003x$	-0.0289	0.5431
9/18-9-27	larvae	$\log_e(y+1)= 1.26+0.0005x$	-0.0007	0.3315
	pupae	$\log_e(y+1)= 1.16+0.0007x$	-0.0093	0.3863
10/04-10/11	larvae	$\log_e(y+1)= 1.00+0.0057x$	0.1264	0.0536
	pupae	$\log_e(y+1)= 1.16+0.0031x$	-0.0291	0.5454
10/25-11/01	larvae	$\log_e(y+1)= 1.33+0.0125x$	-0.0234	0.4983
	pupae	$\log_e(y+1)=0.93+0.0532x$	0.0661	0.1192
Total	larvae	$\log_e(y+1)=1.20+0.0001x$	0.0045	0.3031
	pupae	$\log_e(y+1)=1.08+0.0002x$	-0.0107	0.3967

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

where high population levels in 1992 were followed by extremely low levels in 1993. Egg counts per 100 g of lichen are used presently to predict defoliation levels (<5 healthy eggs = trace defoliation; 5-26 healthy eggs = light defoliation; 27-60 healthy eggs = moderate defoliation; >61 eggs = severe defoliation) (C.S. Wood, pers. comm.). The significant relationships between numbers of males captured and egg populations (Figs. 4,5) and the lack of significance for larval and pupal populations (Table 7), suggests that egg counts may not be good predictors of forthcoming defoliation. However, continued egg sampling is justified to determine levels of parasitism and ratios of old:new eggs.

Dispersal of mated adults (Daterman 1980) may also be associated with the poor relationship between captured males and subsequent larval and pupal numbers. Finally, discrepancies in sample area and accuracy, among the three sampling techniques, as mentioned above, will have contributed to variation in the model.

4.0 CONCLUSIONS

Several conclusions can be reached which will directly facilitate the establishment of a monitoring program for the western hemlock looper, enabling forest managers to detect changes in population density before defoliation is detected.

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

2. Lures containing 10 μg of the two-component blend of isomeric 5,11-dimethylheptadecane and 2,5-dimethylheptadecane will not decline in potency over the flight season, indicating that this dose is sufficient for monitoring purposes.

3. Nonsaturating Unitraps are better suited than sticky traps for monitoring western hemlock looper populations, as sticky traps become saturated when as few as 100 moths are captured. In a monitoring system for the western hemlock looper, traps should be equally effective at different population levels. The use of sticky traps would not achieve this objective.

4. Seasonal trends in trap captures and temperature do not track each other, indicating that temperature is a poor predictor of peak flight, although the usefulness of thermal

sums should be tested in the future as predictors of the onset of flight.

5. Captures of males in 10 µg-baited traps accurately reflect larval and pupal populations within the same generation, validating in part their use as monitoring tools for the next generation.

6. Captures of males in 10 µg-baited traps can be good predictors of egg populations in the subsequent generation, particularly for the beginning of the flight period and for the total flight period.

7. Because numbers of captured males in pheromone-baited traps may predict egg populations, but not larval and pupal populations in the subsequent generation, an early sampling of larval populations may be needed to validate trapping-based predictions before management measures are implemented. Continued egg sampling to indicate the level of parasitism and the ratio of new:old eggs and to allow for lead time before larval sampling is also justified.

8. A pheromone-based monitoring program could be implemented immediately, but validation by other sampling methods for a period of years is necessary before conversion to pheromone-baited traps as a primary monitoring tool.

References

Allen, D.C., L.P. Abrahamson, D.A. Eggen, G.N. Lanier, S.R. Swier, R.S. Kelley, and M. Auger. 1986. Monitoring spruce budworm (Lepidoptera: Tortricidae) populations with pheromone-baited traps. Environ. Entomol. 15: 152-165.

Angerelli, N. and J.A. McLean. 1984. Windtunnel, and field observations of western spruce budworm responses to pheromone-baited traps. J. Entomol. Soc. Brit. Columbia. 8: 10-16.

Anshelevich, L., M. Kehat, E. Dunkelblum, and S. Greenberg. 1993. Sex pheromone traps for monitoring the honeydew moth, *Cryptoblabes gnidiella*: Effect of pheromone components, pheromone dose, field aging of dispenser, and type of trap on male captures. Phytoparasitica 21: 189-198.

Baker, T.C., W. Meyer, W.L. Roelofs. 1981. Sex pheromone dosage and blend specificity of response by Oriental fruit moth males. Entomol. exp. and appl. 30: 267-279.

Bergh, J.C. and W.D. Seabrook. 1986a. A simple technique for indexing the mating status of male spruce budworm, *Choristonerua fumiferana* (Lepidoptera: Tortricidae). Can. Entomol. 118: 37-41.

Bergh, J.C. and W.D. Seabrook. 1986b. The mating status of spruce budworm males, *Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae), caught in pheromone-baited traps. J. Entomol. Sci. 21: 254-262.

Carolin, V.M., N.E. Johnson, P.E. Buffam, and D. McComb. 1964. Sampling egg populations of the western hemlock looper in coastal forests. USDA Forest Serv., Res. Pap. PNW-14, 13pp.

Condrashoff, S.F. 1967. An extraction method for rapid counts of insect eggs and small organisms. Can. Entomol. 99:300-303.

Daterman, G.E. 1980. Pheromone responses of forest lepidoptera: implications for dispersal and pest management. *In:* Proceedings of the 2nd IUFRO conference on dispersal of forest insects: evaluation, theory and management implications. A.A. Berryman and L. Safranyik (eds.). Co-sponsored by the Canadian Forest Service and CANUSA and West Washington State University.

Daterman, G.E. 1982. Monitoring insects with pheromones: trapping objectives and bait formulations. *In:* Insect

suppression with controlled release pheromone systems, Vol. 1, pp. 195-212. A.F. Kydonieus and M. Beroza (eds.). CRC Press, Inc., Boca Raton.

Dewey, J.E., W.M. Ciesla, and R.C. Lood. 1972. Status of the western hemlock looper in the Northern Region, 1972: A potentially devastating forest pest. USDA Forest Service Technical Report 72-10.

Eidt, D.C. and M.D. Cameron 1970. Pretreatment of spruce budworm eggs for counting. Can. For. Serv., Bi-mon. Res. Notes 26:46-47.

Elkinton, J.S. 1987. Changes in efficiency of the pheromone-baited milk-carton trap as it fills with male gypsy moths (Lepidoptera: Lymantriidae). J. Econ. Entomol. 80: 754-757.

Elkinton, J.S. and R.T. Cardé. 1980. Distribution, dispersal and apparent survival of male gypsy moths as determined by capture in pheromone-baited traps. Environ. Entomol. 9: 729-737.

Elkinton, J.S., C. Schal, T. Ono and R.T. Cardé. 1987. Pheromone puff trajectory and upwind flight of gypsy moths in a forest. Physiol. Entomol. 12: 399-406.

Elsey, K.D., J.A. Klun, and M. Schwarz. 1991. Forecasting pickleworm (Lepidoptera: Pyralidae) larval infestations using sex pheromone traps. J. Econ. Entomol. 84: 1837-1841.

Erickson, R.D. 1984. Western hemlock looper. Forestry Canada-Pacific and Yukon Region, Victoria, B.C., Pest Leaflet No. 21.

Erickson, R.D. and R. Ferris. 1992. Forest Insect and Disease Conditions, Cariboo Forest Region-1991. Forestry Canada-Pacific and Yukon Region, Victoria, B.C. FIDS Rep. #92-1.

Faccioli, G., A. Antropoli and E. Pasqualini. 1993. Relationship between males caught with low pheromone doses and larval infestation of *Argyrotaenia pulchellana*. Entomol. exp. appl. 68: 165-170.

Fessenden, R.J. and J.S. Fessenden. 1986. Organic Chemistry, third edition. Brooks/Cole Publishing Company, Monterey.

Furniss, R.L. and V.M. Carolin. 1977. Western Forest Insects. USDA, For. Serv., Misc. Pub. No. 1339.

Granett, J. 1974. Estimation of male mating potential of gypsy moths with disparlure baited traps. Environ.

Entomol. 3: 383-385.

Gray, T.G., R.F. Shepherd and C.S. Wood 1973. A hot-water technique to remove insect eggs from foliage. Can. For. Serv., Bi-mon. Res. Notes 29(5):29.

Gries, G., R. Gries, J.H. Borden, J.Li, K.N. Slessor, G.G.S. King, W.W. Bowers, R.J. West and E.W. Underhill. 1991. 5,11-Dimethylheptadecane and 2,5-dimethylheptadecane: sex pheromone components of the geometrid moth, *Lambdina fiscellaria fiscellaria*. Naturwissenschaften 78:315-317.

Gries, G., R. Gries, S.H. Krannitz, J. Li, G.G. Skip King, K.N. Slessor, J.H. Borden, W.W. Bowers, R.J. West, and E.W. Underhill. 1993. Sex pheromone of the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera:Geometridae). J. Chem. Ecol. 19:1009-1019.

Harris, J.W.E., D.G. Collis and K. M. Magar 1972. Evaluation of the tree-beating method for sampling defoliating forest insects. Can. Entomol. 104:723-729.

Harris, J.W.E., A.F. Dawson and R.G. Brown. 1982. The western hemlock looper in British Columbia, 1911-1980. Environ Canada, Can. Forest. Ser. Pac. Forest Res. Cent. Inf. Rept. BC-X-234, 18pp.

Hopping, G.R. 1934. An account of the western hemlock looper *Ellopia somniaria* Hulst, on conifers in British Columbia. Sci. Agric. 15:12-28.

Houseweart, M.W., D.T. Jennings, and C.J. Sanders. 1981. Variables associated with pheromone traps for monitoring spruce budworm populations (Lepidoptera: Tortricidae). Can. Entomol. 113:527-537.

Howell, J.F., R.S. Schmidt, D.R. Horton, S.U.K. Khattak and L.D. White. 1990. Codling moth: male moth activity in response to pheromone lures and pheromone-baited traps at different elevations within and between trees. Environ. Entomol. 19:573-577.

Hoyt, S.C., P.H. Westigard, and R.E. Rice. 1983. Development of pheromone trapping techniques for male San José scale (Homoptera: Diaspididae). Environ. Entomol. 12: 371-375.

Humphreys, N. and R. Ferris. 1992. Forest Insect and Disease Conditions, Prince George Forest Region-1991. Forestry Canada-Pacific and Yukon Region, Victoria, B.C. FIDS Rep. #92-4.

Jansson, R.K., F.I. Proshold, L.J. Mason, R.R. Heath and S.H. Lecrone. 1990. Monitoring sweetpotato weevil (Coleoptera:Curculionidae) with sex pheromone: effects of dosage and age of septa. Trop. Pest Manage. 36(3):263-269.

Jansson, R.K., L.J. Mason, R.R. Heath, K.A. Sorensen, A.M. Hammond, and J.V. Robinson. 1992. Pheromone-trap monitoring system for sweetpotato weevil (Coleptera:Apionidae) in the southern United States: effects of trap type and pheromone dose. J. Econ. Entomol. 85:416-423.

Jardine, A.K. 1969. Western hemlock looper in British Columbia. Forest Insect and Disease Survey, Forest Pest Leaflet No. 21, Canadian Forestry Service.

Kamm, J.A., L.M. McDonough, and K.E. Rowe. 1989. Effect of dosage and ratio of sex pheromone components on behavior of *Chrysoteuchia topiaria* (Zeller)(Lepidoptera: Pyralidae). Environ. Entomol. 18: 368-372.

Katsoyannos, B.I., N.A. Kouloussis and A. Bassiliou. 1992. Monitoring populations of the almond seed wasp, *Eurytoma anygdali*, with sex pheromone traps and other means, and optimal timing of chemical control. Entomol. exp. appl. 62:9-16.

Kehat, M. and E. Dunkelblum. 1993. Sex pheromones: achievements in monitoring and mating disruption of cotton pests in Israel. Arch. Ins. Biochem. and Physiol. 22: 425-431.

Kinghorn, J.M. 1952. Western hemlock looper egg sampling. Can. Dep. Agric., Bi-mon. Prog. Rept. 8(3):3-4.

Kinghorn, J.M. 1954. The effect of stand composition on the mortality of various conifers, caused by defoliation by the western hemlock looper on Vancouver Island, British Columbia. For. Chron. 30(4):380-400.

Knight, A.L. and B.A. Croft. 1987. Regional population dynamics and seasonal spatial patterns of *Argyrotaenia citrana* (Lepidoptera: Tortricidae) as measured by a pheromone trap grid and larva sampling. Environ. Entomol. 16: 59-67.

Knight, A.L. and L.A. Hull. 1988. Area wide population dynamics of *Platynota idaeusalis* in south central Pennsylvania pome and stone fruits. Environ. Entomol. 17: 1000-1007.

Koot, H.P. and J. Hodge. 1992. Forest Insect and Disease Conditions, Kamloops Forest Region-1991. Forestry Canada-Pacific and Yukon Region, Victoria, B.C.. FIDS Rep. #92-2.

Krannitz, S.H. 1992. A synthetic sex pheromone for the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera:Geometridae). M.P.M. thesis. Simon Fraser University, Burnaby, British Columbia, Canada.

Lejeune, R.R. 1975. Western hemlock looper. *In*: Aerial control of forest insects in Canada: a review of control projects employing chemical and biological insecticides. Prebble, M.L., ed. Canada Department of Environment, Ottawa, p.179.

Lewis, T. and E.D.M. Macaulay. 1976. Design and elevation of sex-attractant traps for pea moth, *Cydia nigricana* (Steph.) and the effect of plume shape on catches. Ecol. Entomol. 1: 175-187.

Li, J., R. Gries, G. Gries, K.N. Slessor, G.G.S. King, W.W. Bowers and R.J. West. 1993a. Chirality of 5,11-dimethylheptadecane, the major sex phromone component of the hemlock looper, *Lambdina fiscellaria* (Lepidoptera: Geometridae). J. Chem. Ecol. 19:1057- 1062.

Li, J., G. Gries, R. Gries, J. Bikic and K.N. Slessor. 1993b. Chirality of synergistic sex pheromone componenets of the western hemlock looper *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera: Geometridae). J. Chem. Ecol. 19: 2547-2561.

Linn, C.E. Jr., M.G. Campbell, and W.L. Roelofs. 1987. Pheromone components and active spaces: what do moths smell and where do they smell it? Science. 237: 650-652.

Linn, C.E., M.G. Campbell, and W.L. Roelofs. 1991. The effects of different blend ratios and temperature on the active space of the Oriental fruit moth sex pheromone. Physiol. Entomol. 16: 211-222.

McBrien, H.L., G.J.R. Judd, and J.H. Borden. 1994. *Campylomma verbasci* (Meyer)(Heteroptera: Miridae): pheromone-based seasonal flight patterns and prediction of nymphal densities in apple orchards. J. Econ. Entomol. in press.

McGuffin, W.C. 1987. Guide to the Geometridae of Canada (Lepidoptera). II. Subfamily Ennominae. 4. Mem. Entomol. Soc. Can. 138:64-65.

McLaughlin, J.R. and R.R. Heath. 1989. Field trapping and

observations of male velvetbean caterpillar moths and trapping of *Mocis* spp. (Lepidoptera: Noctuidae: Catacolinae) with calibrated formulations of sex pheromone.

McNally, P.S. and M.M. Barnes. 1981. Effects of codling moth pheromone trap placement, orientation and density on trap catches. Environ. Entomol. 10:22-26.

McNeil, J.N. 1991. Behavioral ecology of pheromone-mediated communication in moths and its importance in the use of pheromone traps. Annu. Rev. Entomol. 36: 407-430.

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. British Columbia Ministry of Forests Special Report Series No. 6.

Mitchell, E.R., H.R. Agee, and R.R. Heath. 1989. Influence of pheromone trap color and design on capture of male velvetbean caterpillar and fall armyworm moths (Lepidoptera:Noctuidae). J. Chem. Ecol. 15: 1775-1784.

Ostaff, D.P., J.H. Borden, and R.F. Shepherd 1974a. Reproductive biology of *Lambdina fiscellaria lugubrosa* (Lepidoptera:Geometridae). Can. Entomol. 106: 659-665.

Ostaff, D.P., J.H. Borden, and R.F. Shepherd 1974b. Sex attraction and courtship behavior in *Lambdina fiscellaria lugubrosa* (Lepidoptera: Geometridae). Can. Entomol. 106: 493-501.

Otvos, I.S. 1974. A collecting method for pupae of *Lambdina fiscellaria fiscellaria* (Lepidoptera: Geometridae). Can. Entomol. 106:329-331.

Otvos, I.S. and D.G. Bryant. 1972. An extraction method for rapid sampling of eastern hemlock looper eggs, *Lambdina fiscellaria fiscellaria* (Lepidoptera:Geometridae). Can. Entomol. 104:1511-1514.

Phelan, P.L. and T.C. Baker. 1986. Male-size-related courtship success and intersexual selection in the tobacco moth, *Ephestia elutella*. Experientia 42: 1291-1293.

Pitcairn, M.J., F.G. Zalom, and W.J. Bentley. 1990. Weather factors influencing capture of *Cydia pomonella* (Lepidoptera: Torticidae) in pheromone traps during overwintering flight in California. Environ. Entomol. 19: 1253-1258.

Pivnick, K.A., D.L. Barton, and J.G. Millar. 1988. Improved pheromone trap exclusion of the bruce spanworm *Operophtera bruceata* (Hulst) (Lepidoptera:Geometridae) when monitoring winter moth *Operophtera brumata* (L.) populations. Can. Entomol. 120:389-396.

Polavarapu, S. and W.D. Seabrook. 1992. Evaluation of pheromone-baited traps and pheromone lure concentrations for monitoring blueberry leaftier (Lepidoptera: Tortricidae) populations. Can. Entomol. 124: 815-825.

Ramaswamy, S.B., and R.T. Cardé. 1982. Nonsaturating traps and long-life attractant lures for monitoring spruce budworm males. J. Econ. Entomol. 75: 126-129.

Ramaswamy, S.B., R.T. Cardé, and J.A. Witter. 1983. Relationships between catch in pheromone-baited traps and larval density of the spruce budworm, *Choristoneura fumiferana* (Lepidoptera:Tortricidae). Can. Entomol. 115: 1437-1443.

Roelofs, W.L. 1978. Threshold hypothesis for pheromone perception. J. Chem. Ecol. 4:685-699.

Roelofs, W.L. and R.T. Cardé. 1977. Responses of Lepidoptera to synthetic sex pheromone chemicals and their analogues. Ann. Rev. Entomol. 23: 377-405.

Sanders, C.J. 1978. Evaluation of sex attractant traps for monitoring spruce budworm populations (Lepidoptera: Tortricidae). Can. Entomol. 110: 43-50.

Sanders, C.J. 1981. Sex attractant traps: their role in the management of spruce budworm. *In:* Management of insect pests with semiochemicals: concepts and practice. E.R. Mitchell (ed.). Plenum Press, New York, pp. 75-91.

Sanders, C.J. 1986. Evaluation of high-capacity, nonsaturating sex pheromone traps for monitoring population densities of spruce budworm (Lepidoptera: Tortricidae). Can. Entomol. 118: 611-619.

Sanders, C.J. 1988. Monitoring spruce budworm population density with sex pheromone traps. Can Entomol. 120: 175-183.

Sanders, C.J. 1989. The further understanding of pheromones: biological and chemical research for the future. *In:* Insect pheromones in plant protection. A.R. Jutsum and R.F.S. Gordon (eds.). John Wiley and

Sons, Toronto, pp. 323-351.

Sanders, C.J. 1992. Sex pheromone traps for monitoring spruce budworm populations: resolving operational problems. Forestry Canada-Ontario Region-Great Lakes Forestry Centre. Inf. Rep. O-X-425.

Sanders, C.J. and E.A. Meighen. 1987. Controlled-release sex pheromone lures for monitoring spruce budworm populations. Can. Entomol. 119: 305-313.

SAS 1988. SAS User's Guide: Basics, 6.03 ed., SAS Institute Inc., Cary, N.C..

Shelton, A.M. and J.A. Wyman. 1979. Time of tuber infestation and relationships between pheromone catches of adult moths, foliar larval populations and tuber damage by tuberworm. J. Econ. Entomol. 72: 599-601.

Shepherd, R.F. and T.G. Gray. 1972. Solution separation and maximum likelihood density estimates of hemlock looper (Lepidoptera:Geometridae) eggs in moss. Can. Entomol. 104:751-754.

Shepherd, R.F., T.G. Gray, R.J. Chorney and G.E. Daterman. 1985. Pest management of Douglas-fir tussock moth, *Orgyia pseudotsugata* (Lepidoptera: Lymantriidae): monitoring endemic populations with pheromone traps to detect incipient outbreaks. Can. Entomol. 117:839-848.

Shore, T.L. 1989. Sampling western hemlock looper pupae (Lepidoptera: Geometridae) using burlap traps. J. Entomol. Sci. 24(3):348-354.

Shore, T.L. 1990. Recommendations for sampling and extracting the eggs of the western hemlock looper, *Lambdina fiscellaria lugubrosa*, (Lepidoptera:Geometridae). J. Entomol. Soc. Brit. Columbia 87:30-35.

Smith, R.F. and J.H. Borden. 1990. Relationship between fall catches of *Campylomma verbasci* (Heteroptera: Miridae) in traps baited with females and density of nymphs in the spring. J. Econ. Entomol. 83:1506-1509.

Sweeney, J.D. and J.A. McLean. 1990. Effect of sex-pheromone concentration on behavior of three strains of western spruce budworm male moths. J. Chem. Ecol. 16:1531-1546.

Sweeney, J.D., J.A. McLean and L.M. Friskie. 1990a. Roles of minor components in pheromone-mediated behavior of western spruce budworm male moths. J. Chem. Ecol. 16: 1517-1530.

Sweeney, J.D., J.A. McLean, R.F. Shepherd. 1990b. Factors affecting catch in pheromone traps for monitoring the western spruce budworm, *Choristoneura occidentalis* Freeman. Can. Entomol. 122: 1119-1130.

Thistlewood, H.M.A. and R.D. McMullen. 1989. Distribution of *Campylomma verbasci* (Meyer) (Heteroptera: Miridae) nymphs on apple and an assessment of two methods of sampling. J. Econ. Entomol. 82: 510-515.

Thomson, M.G. 1952. Western hemlock looper. Can. Dep. Agric. Bi-mon. Prog. Rept. 8:3.

Thomson, M.G. 1958. Egg sampling for the western hemlock looper. For. Chron. 34(3):248-256.

Tingle, F.C. and E.R. Mitchell. 1981. Relationships between pheromone trap catches of male tobacco budworm, larval infestations, and damage levels in tobacco. J. Econ. Entomol. 74: 437-440.

Turgeon, J.J., J.N. McNeil, and W.L. Roelofs. 1983. Field testing of various parameters for the development of pheromone-based monitoring system for the armyworm, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae). Environ. Entomol. 12: 891-894.

Unger, L. and A.J. Stewart. 1992. Forest Insect and Disease Conditions, Nelson Forest Region-1991. Forestry Canada-Pacific and Yukon Region, Victoria, B.C. FIDS Rep. #92-3.

Van Sickle, G.A. and C.S. Wood. 1988. *In:* Forest Insect and Disease Conditions in Canada-1987. Compiled by B.H. Moody. Forest Insect and Disease Survey, Forestry Canada, Catalogue No. Fo21-1/1987E. p. 86.

Van Sickle, G.A. and C.S. Wood. 1989. *In:* Forest Insect and Disease Conditions in Canada-1988. Compiled by B.H. Moody. Forest Insect and Disease Survey, Forestry Canada, Catalogue No. Fo21-1/1988E. p. 92.

Wall, C. 1989. Monitoring and spray timing. *In:* Insect pheromones in plant protection, A.R. Jutsum and R.F.S. Gordon (eds.). John Wiley and Sons, Toronto, pp.39-67.

Weatherston, I. 1989. Alternative dispensers for trapping and disruption. *In:* Insect pheromones in plant protection, A.R. Jutsum and R.F.S. Gordon (eds.). John Wiley and Sons, Toronto, pp. 249-280.

West, R.J. and W.W. Bowers. 1994. Factors affecting calling behavior by *Lambdina fiscellaria fiscellaria*

(Lepidoptera: Geometridae), under field conditions. Environ. Entomol. 23:122-129.

Winer, B.J., D.R. Brown and K.M. Michels. 1991. Statistical principles in experimental design, 3rd ed.. McGraw-Hill, Inc., Toronto.

Wood, C.S. and G.A. Van Sickle. 1991. Forest Insect and Disease Conditions British Columbia and Yukon-1990. Forestry Canada- Pacific and Yukon Region- Inf. Rep. BC-X-326.

Wood, C.S. and G.A. Van Sickle. 1992. Forest Insect and Disease Conditions British Columbia and Yukon-1991. Forestry Canada-Pacific and Yukon Region- Inf. Rep. BC-X-334.

Wood, C.S. and G.A. Van Sickle. 1993a. Forest Insect and Disease Conditions British Columbia and Yukon-1992. Forestry Canada-Pacific and Yukon Region- Inf. Rep. BC-X-340.

Wood, C.S. and G.A. Van Sickle. 1993b. Forest Insect and Disease Conditions British Columbia and Yukon-1993. Forestry Canada-Pacific and Yukon Region- Inf. Rep. BC-X-345.

Zar, J.H. 1984. Biostatistical analysis, 2nd ed. Prentice Hall, Englewood Cliffs.