University of Alberta

Management of birch leaf miners (Hymenoptera: Tenthredinidae) in northern cities

by

Robin Lesley McQueen ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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To my family

Abstract

Two introduced birch leaf mining sawflies, *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow), were studied to investigate larval mortality agents and adult dispersal patterns. This information was used to develop new and environmentally acceptable management tactics for urban areas.

The specialist parasitoid, *Lathrolestes luteolator* (Gravenhorst) is an important natural control of *P. thomsoni*, and is spreading throughout Alberta. Barriers of weed mat overlaying bare substrate beneath birch trees reduced survivorship of birch leaf miner larvae and *L. luteolator*. This treatment should be used to target *F. pusilla* on small trees. Predation on prepupae and pupae is low in peat, sand and loam substrates; however, on the ground surface, ants are important predators, especially on sandhills. Abrasiveness of sand does not harm larvae, but soil moisture is apparently important for sawfly survival.

Leaf miner adults disperse well and easily locate birch in urban landscapes. Adults can be trapped with yellow, plastic, sticky traps. To maximize catch of *F. pusilla*, traps should be placed on the canopy periphery; to catch *P. thomsoni*, traps can be placed throughout the canopy and on the trunk. Hexanol baits do not increase trap efficiency.

A public survey showed that many people in Edmonton are willing to allow natural controls to function without interference from insecticides. A successful urban pest management plan must educate the public about pest biology and nonchemical controls.

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1. Introduction

1.1 Urban pest management

Urban ecosystems contain highly unnatural combinations of endemic and exotic plant and animal species living in significantly altered abiotic environments. For urban environments created for human enjoyment and public activity, aesthetic quality is deemed important and little pest damage is tolerated (Horn 1988; Paine et al. 1993; Raupp et al. 1988). Intensive maintenance is required to maintain high aesthetic quality, and often relies on man-made substitutes for natural inputs; for example, fertilizers supplant nutrient recycling and insecticides replace predators and parasitoids (Hermes et al. 1984). While these substitutes perform the large scale functions of natural inputs, they disturb many checks and balances that govern complex interactions present in more natural ecosystems. Many such disturbances result from misuse of chemical pesticides in urban environments.

In North America, large volumes of pesticides are used in urban settings (Coats 1994; Funk 1992; Holmes and Davidson 1984; Smith and Raupp 1986). Homeowners often make decisions to apply these chemicals without biological information, (Ball 1986; Horn 1988; Raupp and Noland 1984; Smith and Raupp 1986) resulting in use of pre-scheduled cover sprays instead of well-timed, localized treatments for specific pests. Landscape companies also use non-target, cover sprays to reduce pests, even though they are aware of the problems associated with these types of treatments (Ball 1986). Pesticide overuse results in ecological disruptions such as secondary pest outbreaks, and increased resistance and resurgence of target pests (Barbosa and Wagner

1989; Horn 1988; Raupp and Noland 1984; Smith and Raupp 1986). Additional concerns are potential health hazards which are often more acute in urban settings since people are densely clustered and more at risk of exposure to pesticides (Raupp and Noland 1984). In response to these environmental and health concerns, interest in integrated pest management has spread to urban centers.

Integrated pest management (IPM) is a dynamic decision making process that depends on a variety of preventative, suppressive and regulatory strategies that are ecologically and economically viable and socially acceptable (Barbosa and Wagner 1989; Olkowski et al. 1982). It does not necessarily eliminate pesticides but rather reduces volume and maximizes efficiency. The public is increasingly aware of the economic, environmental and health benefits of IPM and the drawbacks of pesticides. Consequently, the widespread use of pesticides is becoming more socially unacceptable and highly regulated and, eventually, people will need to rely on alternative pest management strategies (Hermes et al. 1984). In response to these needs, my research aims to provide alternatives to insecticides for management of birch leaf miners (Hymenoptera: Tenthredinidae) in urban settings.

1.2 Birch Leaf Miner Damage and Control in the City of Edmonton

Trees are valuable assets in urban ecosystems since they provide shade, privacy, shelter from the wind and enhance property value (Grey and Deneke 1986; Hermes et al. 1984; Nielsen 1982; Phillips 1993). In cities throughout Alberta, birches (*Betula* spp.) are highly prized as ornamental trees. Unfortunately, two species of leaf mining sawflies, *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow) cause serious damage to these trees (Ives and Wong 1988). A third species of birch leaf miner, *Heterarthrus nemoratus* (Fallen), is rare in Alberta. All three species of sawflies were inadvertently introduced from Europe to eastern North America and then spread westward to reach central Alberta before 1970 (Drouin and Wong 1984).

Damage is primarily an aesthetic concern, and has made birch unpopular as ornamentals because of the early discolouration of leaves. Leaf miner infestations usually do not seriously affect the health of a tree (Hahn and Ascerno 1993; Langor et al. 1994; Ives and Wong 1988). However, heavy damage from birch leaf miners over several years can stress birch and increase their susceptibility to dieback caused by drought or attack by other insects or diseases.

European populations of birch leaf miner are apparently held in check by natural enemies, including diverse parasitoid assemblage (Eichhorn and Pschorn-Walcher 1973). In Alberta, 12 species of parasitoids have been reared from *F. pusilla*, but they are not numerous enough to significantly reduce leaf miner populations (Digweed 1995). Nine parasitoids have been reared from *P. thomsoni* but only one appears capable of significantly reducing population levels. This ichneumonid parasitoid, *Lathrolestes luteolator* (Gravenhorst), was discovered in 1994 in conjunction with a drastic drop in the *P. thomsoni* population in Edmonton.

The method of control generally recommended for birch leaf miners is application of systemic insecticides as a soil drench, usually the organophosphate, dimethoate (commercially known as Cygon 2E®). Homeowners often obtain inadequate results because they apply the insecticide incorrectly. Dimethoate is phytotoxic (Drouin and Wong 1984) and consequently, some people damage their trees by over-applying the insecticide. Dimethoate is also toxic to beneficial insects, birds and other wildlife (Wilson Laboratories Inc. 1993), and to humans (Brady 1974). In addition to these drawbacks, homeowners find yearly dimethoate treatments expensive, especially when they fail to provide the expected results. There is a need to provide homeowners with alternative management methods that are economically acceptable and that will greatly reduce use of insecticides. A good understanding of the biology of birch leaf miners is a prerequisite to development of effective management strategies.

1.3 Life History of *Fenusa pusilla* and *Profenusa thomsoni*

In Alberta, *Fenusa pusilla* adults begin to emerge in May (Digweed 1995). After mating, females lay eggs in immature leaves (DeClerck and Shorthouse 1985). Larvae feed on the tissue between the two epidermal layers of the leaf (Ives and Wong 1988). There are four feeding instars and a fifth nonfeeding instar (Jones and Raske 1976). Fifth instar larvae drop to the ground, enter the substrate through cracks or other natural openings and build cocoons. Pupation may occur immediately with second generation adults emerging in late June or sawflies may overwinter as prepupae (pharate pupae). In some years, a small third generation occurs in August (Digweed 1995).

Profenusa thomsoni has only one generation per year and is parthenogenetic. Adults emerge in late June or July (Digweed 1995). This species has five feeding instars and a sixth nonfeeding instar which overwinters in the soil as a prepupa (Ives and Wong 1988; Martin 1960). Its oviposition habits differ from those of *F. pusilla* in that females lay their eggs in mature foliage instead of in new growth.

A common approach to developing a pest management program is to determine vulnerable periods in a pest's life cycle and then focus control activities on these weak points. Both species of birch leaf miner larvae are exposed to a wide array of hazards during the time they are searching for an entrance into the soil. Consequently, much of my research into new management methods focused on the time larvae spend on or in the ground.

1.4 Objectives of this thesis

The overall objective of this research is to develop an urban integrated pest management plan that employs mainly biological and horticultural control procedures. Research discussed in Chapters 2 and 3 primarily focuses on the time larvae spend on the ground or in their cocoons. In Chapter 2, I present information on the capacity of weed mat barriers to reduce survivorship of leaf miner larvae by preventing them from reaching suitable habitats in which to build cocoons. In Chapter 3, I examine larval and pupal mortality factors in an attempt to identify natural controls that could be augmented in urban habitats. Included in Chapter 3 are the results of a survey to determine the distribution of *Lathrolestes luteolator*, an important ichneumonid parasitoid of *P. thomsoni* in Alberta.

Efficiency of pest management plans is often improved when they contend with immigrants. In Chapter 4, I present results from two experiments designed to determine the distance leaf miners are capable of dispersing and if their movement is restricted by patchy distribution of urban birch trees. Also discussed are several aspects of sticky traps that affect catch of adult birch leaf miners, specifically trap material, colour, position and use of an attractant (1-hexanol).

In Chapter 5, I present a pest management plan for birch leaf miners in urban settings. Also included are the results of an Edmonton public opinion survey in which I provided information about *L. luteolator* and then questioned people about their opinions of insecticide use on birch trees. Finally, I give suggestions for future research that may increase efficiency of a birch leaf miner management program.

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2. Evaluation of Weed Mat Barriers for Control of Birch Leaf Miners

2.1 Synopsis

Removal of lawn beneath birch trees and replacement with weed mat overlaid with coarse gravel increases mortality of birch leaf miner larvae in the substrate. However, this treatment also reduces survivorship of *Lathrolestes luteolator* (Gravenhorst), a specialist parasitoid of the sawfly, *Profenusa thomsoni* (Konow). Therefore, it is recommended that weed mat be used only under small and/or transplanted trees to reduce damage by a second species of birch leaf miner, *Fenusa pusilla* (Lepeletier). Gravel must be kept relatively free of soil to maintain effectiveness of the treatment. Weed mat will not damage tree roots by increasing soil temperature.

2.2 Introduction

Two introduced species of birch leaf mining sawflies, *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow), cause serious damage on urban birches in Alberta, Canada. The method of control generally recommended for birch leaf miners is application of systemic insecticides as a soil drench, usually dimethoate (commercially known as Cygon 2E®). This treatment is often ineffective against birch leaf miners and furthermore, dimethoate is toxic to beneficial insects, birds and other wildlife (Wilson Laboratories Inc. 1993) and to humans (Brady 1974). The public is increasingly aware of these drawbacks and is demanding alternatives to insecticides.

Until recently, leaf miner larvae in leaf mines did not suffer high levels of mortality due to natural enemies. However, in the last two years, Edmonton populations of *P. thomsoni* have been attacked heavily by a specialist ichneumonid parasitoid, *Lathrolestes luteolator* (Gravenhorst). Other parasitoids that attack *P. thomsoni* and *F. pusilla* are generalists and do not significantly impact leaf miner populations (Digweed 1995). Until specialist parasitoids are established locally for both species of leaf miner, urban pest management programs would benefit by focusing on consistently vulnerable portions of leaf miner life history.

Once larvae of both species of birch leaf miner finish feeding in protective leaf mines, they drop to the ground and burrow into the substrate to build protective cocoons. They later emerge as a second generation or overwinter as prepupae. Larvae have very little protection from natural enemies while attempting to enter the substrate. Larvae of both species of leaf miners are poor burrowers and, consequently, can spend considerable time on the surface until they find a natural passageway into the substrate. Previous studies have shown that larvae are quite vulnerable during this period. Martin (1960) found that in some locations where hundreds of *P. thomsoni* larvae reached the soil, careful sieving a week or two later yielded few pupal cells. He observed heavy predation by ants (*Formica fusca* L.) on larvae attempting to enter the soil to pupate. Cheng and LeRoux (1966, 1970) observed birds and ants feeding on *F. pusilla* larvae attempting to enter the soil. They also noticed considerable mortality of prepupae and pupae in the soil by comparing the large numbers of larvae entering the soil with the small numbers of emerging adults.

The above observations prompted me to study potential control activities focused on larvae attempting to enter the substrate. Specifically, I investigated the use of weed mat barriers to decrease survivorship of birch leaf mining larvae by preventing them from reaching appropriate habitats to build cocoons. Weed mat is used for landscaping; it allows water to penetrate but prevents weeds from growing (Derr and Appleton 1989). I also monitored the parasitoid *L. luteolator* in this study to establish the impact of weed mat on parasitoid populations.

2.3 Materials and Methods

The impact of weed mat on survivorship of leaf miner larvae was investigated on the University of Alberta campus using six birch trees, three growing in bare soil and three surrounded by sod. In the spring of 1994, the circle of ground beneath each tree canopy was divided in half and, if sod was present, it was removed from one half. Weed mat was placed over bare soil in one half under each tree and covered with an overlay of coarse (four inch) red shale. Depth of shale varied from 3 - 6 cm under each tree and completely covered the weed mat to prevent it from degrading in ultra-violet light. To monitor leaf miner and *L. luteolator* emergence, I placed four square emergence traps, each covering 0.22 m^2 of ground, under each of five trees, two on the treatment half and two on the control half. The sixth tree was small and only one trap could be placed in each half. In 1994, traps were left under trees from May to August, then removed for the winter and returned under the same trees from May to August, 1995. In 1995, traps were placed in different positions from the previous year since overwintered larvae would not be present in ground covered by traps in 1994. I emptied traps daily during emergence periods and tallied the numbers of *F. pusilla*, *P. thomsoni*, and *L. luteolator*. Differences in emergence between treated and untreated ground were analyzed with Chi-square tests.

To determine if weed mat increases soil temperature, a potential health hazard for shallow birch roots, I used a soil thermometer to measure ground temperatures. During the afternoon of July 24th, 1995, I took three separate measurements of temperature, 2.5 cm under the surface in both shaded and unshaded sections of each treated and untreated half under each tree. Paired t-tests ($\alpha=0.05$) were used to determine if significant differences in soil temperature existed under any of the six trees.

2.4 Results

Total emergence was low in 1994 and 1995 (Table 2-1), therefore, numbers of *F. pusilla*, *P. thomsoni* and *L. luteolator* caught in emergence traps were grouped for Chi-square analysis. Where two emergence traps were used in a treated or untreated section, catches for both traps were combined for analysis. Trees from which no leaf miner or parasitoid adults were trapped were excluded from analysis. In 1994, no adults emerged from treated areas (Table 2-1a) which was significantly lower than that from controls ($\chi^2=13.0$, d.f.=3, $p<0.01$). In 1995, two *F. pusilla* adults and one parasitoid were trapped in treated areas, (Table 2-1b), but this was still significantly lower than controls ($\chi^2=19.5$, d.f.=4, $p<0.01$).

Average soil temperature under weed mat was 0.4 to 4.1°C lower than in untreated sections (Table 2-2), but this difference was not significant under any of the six trees. On the day soil temperature was measured, maximum ambient temperature was 22.4 °C (Environment Canada 1995).

2.5 Discussion

Different types of barriers have been studied as potential controls for several pests, including barriers of pesticides (Su et al. 1993), mesh cages (Lawson et al. 1994) and polyethylene soil covers (Keularts and Lindquist 1989). Barriers of weed mat appear to be effective in reducing survivorship of birch leaf miner larvae and pupae below birches in urban settings (Table 2-1). However, effectiveness will be reduced if the gravel covering weed mat is not kept clean. In July, 1995, two second generation *F. pusilla* adults were caught in traps placed on weed mat below one tree (Table 2-1b). Enough soil had fallen into the gravel to allow grass to grow, and birch leaf miners were able to build cocoons. This highlights the importance of keeping the gravel as clean as possible. Cleanliness may be facilitated by keeping the gravel as shallow as possible and using a leaf blower to remove debris. Also, to be effective, weed mat must cover all of the ground directly under tree canopies so that no larvae escape to suitable habitats. This would require large amounts of lawn to be removed, especially under large birch trees. Consequently, this treatment would be most feasible for small trees. Gravel and weed mat would also be easier to keep clean and maintain under smaller trees.

Weed mat will not compromise tree health by increasing underlying soil temperature and damaging roots. However, caution must be exercised when removing sod below birch so as not to damage shallow roots by careless digging.

Unfortunately, this control method also reduces survivorship of the parasitoid, *Lathrolestes luteolator.* In fact, in 1995 this control appears to have killed more parasitoids than birch leaf miners (Table 2-1b). It is also expected that this method will reduce survivorship of *Lathrolestes nigricollis*, a specialist parasitoid of *F. pusilla*, that was introduced from Europe to two sites in Edmonton and is now apparently established in at least one site (Digweed, pers. comm.).

In 1995, most noticeable leaf miner damage on Edmonton trees was caused by *F. pusilla.* Leaf mines of *F. pusilla* occur on new growth (DeClerck and Shorthouse 1985) and are therefore more noticeable on small trees than on large trees where damage is concentrated high in the canopy. Since homeowners seem most aware of aesthetic damage from *F. pusilla* on small trees, I suggest that weed mat be used only under young and/or newly transplanted trees. This will provide a nonchemical alternative until specialist parasitoids of *F. pusilla* are widely established throughout the province. Limiting treatment to small trees will also lessen the impact of control on *L. luteolator.*

Finally, this treatment only reduces resident birch leaf miners. Immigrants from untreated areas may still cause high levels of damage. Yellow sticky traps may help to lessen the impact of immigrants (Chapter 4).

Table 2-1. Total number of *F. pusilla*, *P. thomsoni* and *L. luteolator* adults caught in emergence traps on untreated (control) and treated (weed mat) ground under each tree in 1994 (a) and 1995 (b). No specimens were collected from tree 4 in 1994 or from tree 6 in either year.

a.

tree	untreated	treated
1	17	0
2	2	0
3	2	0
5	5	0
total	26	0
species total	5 *F. pusilla* 19 *P. thomsoni* 2 *L. luteolator*	

b.

tree	untreated	treated
1	26	0
2	1	1
3	0	2
4	6	0
5	5	0
total	38	3
species total	3 *F. pusilla* 2 *P. thomsoni* 33 *L. luteolator*	2 *F. pusilla* 1 *L. luteolator*

Table 2-2. Mean (±SE) temperature (°C) of soil in untreated (control) and treated (weed mat) sections beneath six birch trees, measured July 24th, 1995. Paired t-tests (α=0.05) showed no significant differences between untreated and treated sections any of the six trees.

Tree	untreated (n=3)	treated (n=3)	p
1	18.4±0.5	17.4±0.35	0.358
2	23.3±2.3	19.2±0.20	0.203
3	26.3±1.4	23.0±0.90	0.251
4	18.7±0.4	18.3±0.32	0.504
5	20.1±0.1	18.4±0.72	0.154
6	25.8±4.0	23.0±1.00	0.511

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3. Larval and Pupal Mortality of Birch Leaf Mining Sawflies

3.1 Synopsis

Larvae and pupae of two species of birch leaf mining sawflies, *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow), were studied to determine the influence of three substrate types, sand, peat and loam, on survival of leaf miner larvae on the soil surface and in cocoons. Predation on prepupae and pupae in cocoons appears to be minimal in all three substrates. However, ants are important predators of leaf miner larvae that are attempting to burrow, especially on sandhills where ants are abundant and leaf miner larvae cannot easily enter sand substrate and escape. In contrast to sandhills, ant predation is lower on peatland where larvae can enter the loosely packed substrate with ease. Abrasiveness of sand does not harm larvae, but soil moisture is apparently important for sawfly survival.

A newly discovered parasitoid, *Lathrolestes luteolator* (Gravenhorst) is apparently responsible for a drastic reduction in Edmonton populations of the most damaging species of leaf mining sawfly, *P. thomsoni*. Evidently, *L. luteolator* is in different stages of colonization throughout Alberta.

3.2 Introduction

Two species of birch leaf mining sawflies, *Fenusa pusilla* (Lepeletier), and *Profenusa thomsoni* (Konow), cause damage on urban birches. In Alberta, *P. thomsoni* is the most destructive species of birch leaf miner. Both species were introduced from Europe to eastern North America and spread to Alberta before 1970 (Drouin and Wong 1984). The method of control generally recommended for birch leaf miners is application of systemic insecticides, usually dimethoate, as a soil drench. This treatment is often ineffective against birch leaf miners and is also toxic to beneficial insects, birds and other wildlife (Wilson Laboratories Inc. 1993) and to humans (Brady 1974). Consequently, there is need for environmentally acceptable methods of management for these insects. An understanding of the biology of a pest and its natural mortality agents is an important prerequisite to developing new and effective management tactics (Nealis 1991).

In Alberta, *F. pusilla* adults begin to emerge in May (Digweed 1995). After mating, females lay eggs in immature leaves (DeClerck and Shorthouse 1985). Larvae create brown, blotch-shaped mines by feeding on the inner tissue of leaves. There are four feeding instars and a fifth nonfeeding instar (Jones and Raske 1976). Fifth instar larvae drop to the ground, enter the substrate through cracks or other natural openings and build oval cocoons from substrate particles. Pupation may occur immediately, with second generation adults emerging in late June, or leaf miners may overwinter as prepupae (pharate pupae). In some years, a third generation occurs in August. *Profenusa thomsoni* has only one generation per year and is parthenogenetic. Adults emerge in late June or July. This species has five feeding instars and a sixth nonfeeding instar which overwinters in soil as a prepupa (Ives and Wong 1988; Martin 1960). Its oviposition habits differ from those of *F. pusilla* in that females lay their eggs in mature foliage instead of new growth.

Previous work indicates that birch leaf miner larvae are vulnerable when searching for a passageway into the substrate and in their cocoons. Martin (1960) reported high mortality of *P. thomsoni* larvae, mainly caused by predation by the ant species *Formica fusca* L. on the substrate surface. Cheng and LeRoux (1966, 1970) observed birds and ants feeding on *F. pusilla* larvae attempting to enter the soil. They also noticed considerable mortality of prepupae and pupae in the substrate by measuring large numbers of larvae entering the soil and comparing this to the small numbers of adults emerging from the soil.

Insects which spend part of their lifecycle in the soil are likely to be affected either directly or indirectly by physical or chemical properties of the substrate. For example, substrate type, particle size and moisture influence survival of pupae of *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae) (Oetting 1983; Keularts and Lindquist 1989). These studies have contributed to pest management programs for *L. trifolii*, a pest of many ornamental and agricultural plants, by providing substrate manipulation techniques that reduce survivorship. Differences between substrate types with respect to their influence on birch leaf miner mortality were suspected, based on observations of damage levels on Edmonton trees in July, 1992. Trees on sandhills suffered 0-20% defoliation, those on peatland, 60-80%, and those on loam soils common in urban yards and parks suffered 40-90% defoliation (McQueen, unpublished). Investigation of the influence of substrate on survival might provide insight into birch leaf miner population dynamics and identify potential new pest management options.

Predation and parasitism of *F. pusilla* and *P. thomsoni* eggs and larvae in birch leaves have been well studied (Martin 1960; Cheng and LeRoux 1969; Eichhorn and Pschorn-Walcher 1973; Pschorn-Walcher and Altenhofer 1989; Schönrogge and Altenhofer 1992; Pezzolesi and Hager 1994; Digweed 1995). In Alberta, a diverse assemblage of native generalist predators and parasitoids attack both birch leaf miner species (Digweed 1995). However, high levels of damage in the City of Edmonton prior to 1994 indicated that these generalists were not effective at controlling birch leaf miner populations in urban settings.

Exotic parasitoids, *Lathrolestes nigricollis* (Thomson) and *Grypocentrus albipes* Ruthe (Hymenoptera: Ichneumonidae), were introduced from Europe to North America to help regulate *F. pusilla* (Raske and Jones 1975; Fuester et al. 1984). *Lathrolestes nigricollis* is now established in several areas in eastern North America (Fuester et al. 1984; Van Driesche 1989; Barron 1994) and at one release site in Alberta (Digweed, Langor and Spence unpublished). Because it was introduced into Alberta only recently, *L. nigricollis* is not yet widespread enough to impact *F. pusilla* populations. Until recently, no specialist parasitoid was reported for *P. thomsoni*. This was atypical in that it was the only sawfly species in the Fenusini group that was not attacked by a highly specialist parasitoid species of *Lathrolestes* or *Grypocentrus* (Schonrögge and Altenhofer 1992). However, in 1994, Scott Digweed and I discovered *Lathrolestes luteolator* (Gravenhorst) attacking *P. thomsoni* larvae. This discovery coincided with a drastic reduction in *P. thomsoni* populations in Edmonton.

In order to better understand population dynamics of birch leaf miners and assess potential new management options, I sought to identify natural mortality agents that act upon larvae attempting to burrow into the substrate as well as on prepupae in cocoons. I examined mortality in loam, sand and peat substrates to determine if differences in mortality agents existed between substrates. To assess the potential of *L. luteolator* for controlling *P. thomsoni* throughout Alberta, I aimed to determine the distribution of *L. luteolator* and the relationship between parasitoid and host abundance.

3.3 Materials and Methods

3.3.1 Mortality of prepupae and pupae in different substrates

3.3.1.1 Comparison of total mortality between substrate types

In 1993, an experiment was established to ascertain mortality of overwintering *P. thomsoni* prepupae in three substrate types. Sixteen containers were constructed from 2.5 cm wire mesh to allow access by invertebrate predators. Another 16 were made from plastic containers (11 cm in diameter and 8 cm in depth), with a hole cut in the bottom and covered with fine mesh to allow drainage but exclude predators. Predators were prevented from entering the top of the closed containers by plastic lids and fine mesh. The 'closed' and 'open' containers held the same amount of substrate. Containers were assigned to four sets, each comprised of four open and four closed containers. Three sets were placed in one urban yard, one in sand (a 20 year old sandbox converted into a garden) and two in loam with clay content and sod cover, one set close to a birch tree but not under the dripline, the other about 9 m from birch. The two sets in loam were set up to test whether adult emergence was affected by proximity to birch trees. Each container was filled with the same substrate in which it was placed. Containers in the fourth set were filled with peat and placed in peatland on the outskirts of Edmonton. In the laboratory, ten larvae were placed in each container and given time to build cocoons in the absence of ground predators (minimum of 24 hours), before containers were placed in the ground and left to overwinter. The following summer, I collected emerging *P. thomsoni* and *L. luteolator* adults with emergence traps (11 cm in diameter) placed over each container.

After emergence was complete, cocoons were collected from the substrate. Cocoon extraction was aided by breaking up the substrate, adding water and gently stirring the mixture on a electromagnetic stir plate. Sparkleen™ was added to soil with high clay content to disperse soil particles (Southwood 1978). Cocoons from which adult birch leaf miners emerged had a round emergence hole in one end. Larvae parasitized by *L. luteolator* included: whole cocoons with an emergence hole in one end and a white, silky parasitoid cocoon inside; whole cocoons with a dead *L. luteolator* adult or larva inside; fragmented cocoons with attached portions of parasitoid cocoons. Other cocoons contained dry sawfly prepupae (primarily cuticle), dead sawfly adults or were empty. Reasons for this mortality may include predation, desiccation, unsuccessful pupal emergence or microbial infection. Other cocoons contained dead but plump larvae. It is suspected that these larvae were destined to remain in the soil to overwinter a second time but were killed due to drying of the soil in the laboratory prior to extraction of cocoons. Broken cocoons were reconstructed from fragments. Fate of leaf miners in fragmented cocoons could not be determined. However, these cocoons likely represent adult leaf miners that successfully emerged or prepupae killed by unknown causes, possibly predation or desiccation. In some containers not all larvae could be accounted for by presence of cocoons. Either these cocoons were not constructed or they were not found. These missing cocoons do not represent mortality due to predation during the time larvae were entering the soil since this took place in the lab in the absence of ground predators.

3.3.1.2 Comparison of predation between sites with different substrates

In 1995, a second experiment was set up to further investigate effect of substrate on predation at three sites, the University of Alberta campus (loam site), and two birch stands on the outskirts of Edmonton, one on a large sandhill and the other growing in peatland.

In early August, second generation, mature *F. pusilla* larvae were collected and allowed to pupate in the lab in a sterilized mixture of 25% sifted peat and 75% sand. In mid-August, I placed substrate from each of the three sites in containers made from 2.5 cm wire mesh with four containers for each substrate. I sifted cocoons from the peat and sand mixture and tied a piece of white cotton thread around each undamaged cocoon to facilitate location following experimental treatment. Three cocoons were placed 2.5 cm deep in the substrate of each container. The ends of the thread protruded from the soil and were tied to the wire mesh. On August 16th, I buried one container in substrate under each of four birch trees at each site. After 14 days, I retrieved the containers, excavated the cocoons and examined them under a microscope. Cocoons not preyed on included those with an adult emergence hole and those with a whole prepupa or pupa inside. Damaged cocoons containing birch leaf miners that were dry or partly missing were assumed to have been preyed upon.

3.3.2 Predation on larvae attempting to burrow into substrate

Extent of invertebrate predation of birch leaf miner larvae on the surface of different substrates was investigated in late June, 1995, at the same three sites where cocoon predation was studied (see 3.3.1.2). Containers which prevented escape of birch leaf miner larvae but allowed access to predators were constructed from plastic lids, 11 cm in diameter with 7 mm raised edges. I attached a cardboard ridge to the top of the raised edge so that there was a 0.5 cm inner overhang on each lid. To ensure that small predators could escape, a small cardboard ramp was constructed from the 'floor' of the lid to the overhang and attached with glue. Birch leaf miner larvae could not climb this ramp or hide underneath. Each lid was anchored to the ground by a nail driven through its centre and into the substrate. To prevent desiccation of larvae, a round piece of weed mat (5 cm in diameter) covering a small wad of cotton wool was fixed to the floor of the lid over the nail head with silicone and the cotton was moistened. I placed five *F. pusilla* larvae in each lid and placed one lid under each of four birch trees at each of the three sites. An elevated wooden cover was placed over each lid to provide shade from the hot sun and to prevent bird predation. In the vicinity of each lid (1-2 m away), I placed a pitfall trap in the ground to monitor ground predators active during the experiment. After 3 hours, I gathered the lids and tallied the number of remaining larvae. Arthropods collected in pitfall catches were identified.

In addition to this experiment, direct observations of predation of *F. pusilla* larvae on the substrate surface were made. On June 29th, 1995, I dropped five larvae on the substrate surface under two trees at each of the three sites, and monitored predation. The time required for larvae to burrow completely into the substrate or under clumps of vegetation, or to be captured by an invertebrate predator was measured.

Data from experiments in sections 3.3.1 and 3.3.2 were analyzed with SAS, general linear models procedure (SAS Institute 1988). ANOVA was used to determine if mortality differed between substrates and specific pairwise comparisons between substrates were made with *a-posteriori* t-tests using least squared means.

3.3.3 Distribution of the parasitoid, *Lathrolestes luteolator*

In response to the discovery of *Lathrolestes luteolator* in the City of Edmonton, I conducted a small survey to determine the distribution of this parasitoid in Alberta. Data were collected from eight locations, seven in Alberta and one in Saskatchewan (Figure 3-1). One to three birch trees were monitored at each site (Table 3-1). Monitored trees were 4 - 12 m high and had not been treated with insecticides for at least two years previous, except in Edmonton where trees were not treated in 1995. Beginning on June 30th, one sticky trap was placed on the outer edge of each tree canopy, 1.5 - 2 m from the ground and traps were changed every 7 days for 4 weeks. After the traps were returned by collaborators, I tallied birch leaf miner and *L. luteolator* adults. Traps were also deployed in Yellowknife, Northwest Territories and Lloydminster, Alberta but these were not returned.

3.4 Results

3.4.1 Mortality of prepupae and pupae in different substrates

3.4.1.1 Comparison of total mortality between substrate types

In 1994, 27 *P. thomsoni* adults and 23 *L. luteolator* adults emerged from the 32 containers, 16% of total possible emergence. Emergence of both leaf miners and parasitoids is underestimated because of faulty design of emergence trap heads used to catch adults. Data collected from examination of cocoons provided a more accurate estimate of survivorship.

I located 246 cocoons out of a possible 320, a 77% recovery rate. Adult leaf miners had emerged successfully from 26.0% of cocoons. Only 1.2% of cocoons contained larvae presumed destined to overwinter a second time. The major identifiable source of mortality was parasitism by *L. luteolator* (24.0%); of these parasitized cocoons, 25% contained dead parasitoids. In 24.0% of cocoons, most sources of mortality could not be clearly identified; unsuccessful emergence accounted for 5% of mortality while 90% of remaining cocoons contained dry larvae (primarily cuticle) (90%) and 5% were empty. Lastly, for 24.8% of cocoons, the fate of leaf miners could not be determined because the cocoons were too fragmented.

Overall, ANOVA showed no significant differences between open, wire mesh containers and closed, plastic containers with respect to number of survivors, number of deaths from unknown causes, or number of fragmented cocoons (Table 3-2).

ANOVA showed significant differences between substrates in the number of deaths from unknown causes (Table 3-2A). *A-posteriori* t-tests showed mortality in peat was significantly lower than in sand (p=0.0125), and in loam under birch (p=0.0047) (Table 3-3).

There were significant differences in numbers of fragmented cocoons between substrates (Table 3-2B). *A-posteriori* t-tests showed that peat had significantly more fragmented cocoons than sand (p=0.0009), loam under birch (p=0.0039) and loam away from birch (p=0.0039) (Table 3-3).

ANOVA also showed that the number of survivors significantly differed between substrates (Table 3-2C). *A-posteriori* pairwise comparisons showed containers in loam away from birch had significantly more survivors than containers in sand (p=0.0093) and in loam under birch (0.0053) (Table 3-3).

3.4.1.2 Comparison of predation between sites with different substrates

There were no significant differences between substrates in number of cocoons that were preyed upon (F=0.60, d.f.=2, 6, p=0.5787). The four containers in loam had a mean (±SE) of 0.25 ± 0.250 cocoons that suffered predation (8% of total) while sand and peat each had means of 0.75 ± 0.479 (25% of total).

3.4.2 Predation on larvae attempting to burrow into substrate

All 20 larvae were taken by predators within three hours from both the sandhill and loam sites while a total of 12 larvae remained at the peat site. Differences between sites were significant (F=7.71, d.f.=2, 3, p=0.0220) and *a-posteriori* t-tests show that larval survival was significantly higher on peat than on either sand (p=0.0145) or loam (p=0.0145) (Table 3-4).

The maximum temperature during the experiment was 23.3°C (Environment Canada 1995) and there was an abundance of insect activity. Ants from the subfamilies Formicinae (*Formica* sp.) and Myrmicinae were the most abundant predators caught in pitfall traps at the loam and sandhill sites, comprising 80% and 83%, respectively, of total pitfall catch (Table 3-4). In pitfall traps placed in peatland, ants made up only 43% of total catch, and few of the remaining arthropods were predaceous except for a small number of spiders.

I observed predation only on the sandhill. In total, seven of ten larvae were captured by ants (subfamilies Formicinae and Myrmicinae), six of which were taken by ants within 5 minutes and 21 seconds. One leaf miner larva escaped under a solid clump of vegetation within 16 minutes, but was then abruptly removed from its refuge by a roving ant. Two of the surviving three larvae escaped under debris within 15 minutes after release and the third escaped into the sand after 21 minutes.

Seven of the ten larvae dropped under trees on loam at the university campus escaped into the substrate or under clumps of vegetation within 4 minutes. Two others took 8 and 9 minutes and the last took over half an hour to burrow. At the peat site, seven larvae completely burrowed into the substrate within 2 minutes and 15 seconds. The other three burrowed into the peat within 7 minutes. I observed an ant stop to investigate a larva but refrain from picking it up at both the peat and loam sites. Maximum temperature on the day of these observations was 22.2°C (Environment Canada 1995) and there was an abundance of insect activity.

3.4.3 Distribution of the parasitoid, *Lathrolestes luteolator*

Lathrolestes luteolator adults were trapped in Sir Winston Churchill Provincial Park, and the cities of Edmonton, Calgary and Fort McMurray (Figure 3-1). The ratio of parasitoids to *P. thomsoni* was low in Calgary (1 : 1.5) and even lower in Fort McMurray (1 : 5.4). Parasitoids outnumbered *P. thomsoni* in Edmonton (2.5 : 1) and Sir Winston Churchill Provincial Park (28.7 : 1). The data from this survey suggests that as the local density of *P. thomsoni* decreased, the female:male ratio of *L. luteolator* also decreased (Table 3-1).

3.5 Discussion

3.5.1 Mortality of prepupae and pupae in different substrates

Predation on cocoons appears minimal and is not a major factor regulating leaf miner populations in Edmonton. Mortality did not significantly differ between containers open to predators and closed containers, indicating that mortality was due to factors other than predation. In 1995, when cocoons were exposed to soil predators for two weeks, there were no significant differences in number of cocoons attacked between the sandhill, peatland or loam site. Since 1991, I have observed very low levels of damage from birch leaf miners on birch trees growing on sandhills compared to birch growing in peat or in loam soils common to urban yards and the University campus. If predation on cocoons was important in reducing levels of damage on sandhills, I would expect to have demonstrated higher levels of predation on cocoons in sand than in the other two substrates (peat and loam), even after only two weeks of exposure.

Moisture is important for sawfly survival while they are in cocoons. *Fenusa pusilla* cocoons will rupture in dry weather resulting in desiccation of the larvae (Cheng and LeRoux 1970). Peatland had the fewest number of cocoons in which larvae suffered mortality from unknown causes. If this mortality resulted from desiccation, high moisture levels in peat may have prevented deaths. However, excess moisture often enhances infection by pathogens in soil inhabiting insects as was found with prepupae of *Liriomyza trifolii* (Diptera: Agromyzidae) (Keularts and Lindquist 1989). Nonetheless, earlier observations indicated that excess moisture is not detrimental to birch leaf mining sawflies. In 1991, the peatland was heavily flooded until early June and yet leaf miner adults were captured with emergence traps after the water receded. Since birch are adapted to northern areas with cool, moist forest soils (Hermes et al. 1984; Nielsen 1975), such as peatland, it is reasonable to expect that birch leaf miners should also flourish in conditions ideal for their hosts.

It appears that abrasiveness of sand does not increase mortality of leaf miners. *Fenusa pusilla* (Braker 1986) and *Profenusa alumna* (Labonte and

Lipovsky 1984) have been successfully reared in sand substrate. Also, Oetting (1983) found that when the leaf miner, *Liriomyza trifolii*, was reared in several substrates (sand, clay loam, peat, potting media and gravel), sand had the highest percentage of survival. In these three previous studies, the sand was kept moist, suggesting that soil moisture is more critical to survival of prepupae than physical abrasiveness of the substrate or predation on cocoons.

Survivorship was significantly higher in containers in loam away from birch than in loam under birch (Table 3-2). The greater number of deaths in loam under birch might have been caused by either inadequate soil conditions such as low soil moisture, or by a defense mechanism of birch potentially mediated by chemicals from tree roots which leach into surrounding soil. Defense responses have been demonstrated in birch foliage after damage of adjacent leaves and on trees defoliated in the previous year (Haukioja and Niemelä 1979). More research is needed to determine if defense responses also act against overwintering leaf miners in underlying substrate.

3.5.2 Predation on larvae attempting to burrow into substrate

Evidently, predation on the soil surface by ants is a major factor in the maintenance of low damage levels on birch trees growing on the sandhill. Moreover, the compact nature of sand results in few passageways into the substrate for escape and larvae are therefore even more susceptible to predation. Cheng and LeRoux (1970) also attributed large amounts of mortality of *F. pusilla* larvae to impenetrable soil and attack by ants. In contrast, the peat site which suffers from high levels of leaf miner damage, provides an ideal habitat because of small ant populations and the moist, uncompacted substrate allows larvae to burrow quickly.

3.5.3 Distribution of the parasitoid, *Lathrolestes luteolator*

In eastern North America, *L. luteolator* attacks two oak leaf mining sawflies, the pear slug, *Caliroa cerasi* (L.) and the red oak leaf miner, *Profenusa alumna* (Barron 1994). Barron (1994) suggested that in western Canada where oak is rare, *L. luteolator* switches to the birch leaf mining sawfly, *P. thomsoni*. *Lathrolestes luteolator* appears to be an important natural control of *P. thomsoni*, and is apparently in different stages of colonization throughout the province. Numbers of leaf miners and parasitoids trapped are not necessarily comparable between locations since different numbers of trees were sampled and small numbers of traps were used (Table 3-1). The population ratio between *P. thomsoni* and *L. luteolator* and the sex ratio of *L. luteolator* are likely more indicative of parasitoid population status.

Several factors influence sex ratios of parasitoids including number of progeny per host, decreasing host size, age or quality and host density (King 1987). Apparently, as *P. thomsoni* density decreases, the female:male ratio of *L. luteolator* also decreases. The relationship between host density and sex ratio is not consistent across parasitoid species (King 1987). Host density will affect parasiotid sex ratios if females tend to oviposit male eggs first. At low densities, oviposition bouts will be shorter, and consequently, more males will be produced. A different scenario is that as hosts become scarce, female parasitoids produce more sons, increasing the probability that one of her sons will mate with a female that successfully locates a host for oviposition. Further studies are needed to determine the relationship between host density and sex ratio of *L. luteolator*.

Future studies should use additional trapping methods such as emergence traps since yellow sticky traps appear to be more attractive to *L.*

luteolator than to *P. thomsoni* (Digweed 1995). Use of different trapping methods is especially crucial for studies of parasitoid sex ratios since there may also be differential attraction of male and female wasps to sticky traps. The towns of Fort McMurray and Slave Lake provide ideal locations for continued study of the progression of *L. luteolator* and its interactions with *P. thomsoni.* Populations of *L. luteolator* are still building in Fort McMurray and could be introduced to Slave Lake.

When the specialist parasitoids of *P. thomsoni* and *F. pusilla* (*L. nigricollis*) are well established throughout Alberta, management programs for birch leaf miners should concentrate on educating the public about these natural controls. People need to realize that effectiveness of natural controls is often compromised by insecticides. Parasitic ichneumonids, like *Lathrolestes* spp., are among the most sensitive of all insects to organophosphate insecticides (Horn 1988) such as dimethoate which is commonly used against birch leaf miners.

Table 3-1. Numbers of *Profenusa thomsoni*, *Fenusa pusilla*, and male and female *Lathrolestes luteolator* adults trapped at eight locations in 1995.

Location (# of trees monitored)	Female *L. luteolator*	Male *L. luteolator*	*P. thomsoni*	*F. pusilla*
Fort McMurray (n=1)	18	43	329	2
Sir Winston Churchill Provincial campground (n=2)	2	314	11	0
Touchwood Lake Campground (n=2)	0	0	2	1
Slave Lake (n=1)	0	0	724	0
Edmonton (n=3)	47	202	98	14
Calgary (n=3)	4	13	26	11
Lethbridge (n=1)	0	0	1	0
Saskatoon (n=1)	0	0	1	37

Table 3-2. Analyses of variance evaluating numbers of recovered *P. thomsoni* cocoons buried in four different substrates in containers either open or closed to predators. A, cocoons which showed mortality from unknown causes; B, fragmented cocoons; C, survivors.

A.

Source	df	MS	F	p
Substrate	3	5.7	3.94	0.0204
Container	1	3.8	2.61	0.1192
Substrate x Container	3	3.5	2.44	0.0891
Error	24	34.8		

B.

Source	df	MS	F	p
Substrate	3	9.3	5.90	0.0036
Container	1	5.3	3.36	0.0793
Substrate x Container	3	1.3	0.81	0.4984
Error	24	37.8		

C.

Source	df	MS	F	p
Substrate	3	4.4	3.93	0.0206
Container	1	4.5	4.00	0.0569
Substrate x Container	3	0.4	0.37	0.7751
Error	24	27.0		

Table 3-3. Mean (±SE) of *P. thomsoni* cocoons recovered in each substrate that were fragmented, or showed survivorship or mortality from unknown causes. Means followed by the same letter are not significantly different.

substrate	survivors (n=8)*	mortality-unknown (n=8)	fragmented cocoons (n=8)
peat	2.1±0.48 ab	0.8±0.25 a	3.5±0.65 a
sand	1.5±0.33 a	2.4±0.60 b	1.1±0.30 b
loam away from birch	3.0±0.38 b	1.6±0.46 ab	1.5±0.46 b
loam under birch	1.4±0.32 a	2.6±0.50 b	1.5±0.33 b

* eight containers in each substrate, ten larvae in each container

Table 3-4. Mean (±SE) of *F. pusilla* larvae remaining after being exposed to ground predators for three hours and the mean number of ants caught in pitfall traps on each substrate type. Five larvae and one pitfall trap were placed under each of four birch trees at each site.

Substrate	*F. pusilla* larvae (n=4)	Ants captured (n=4)
loam	0	8 ± 1.5
sand	0	18 ± 5.0
peat	3 ± 1.1	4 ± 4.3

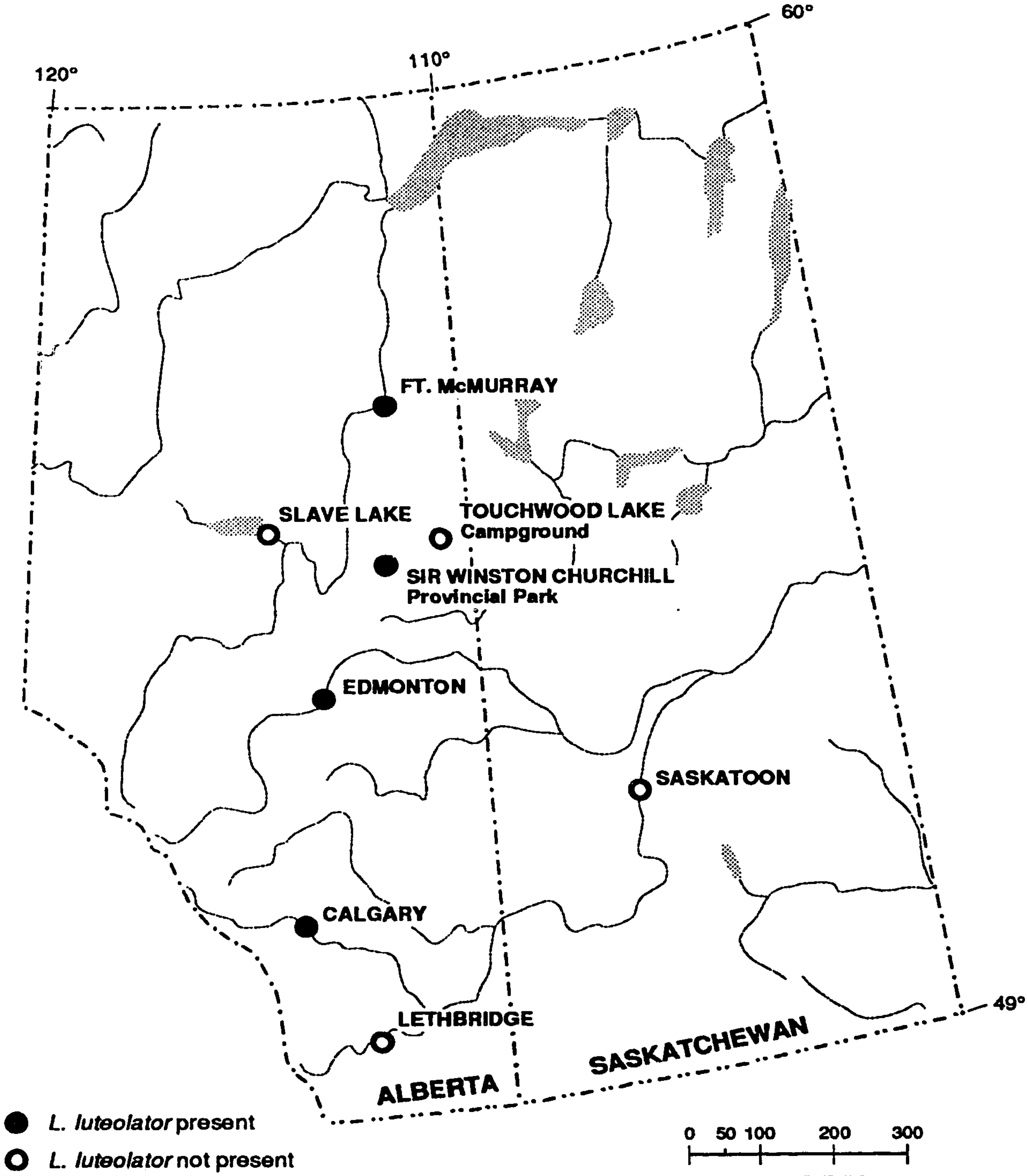

Figure 3-1. Locations monitored for *Lathrolestes luteolator* in 1995.

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4. Dispersal of birch leaf miners in urban neighborhoods and recommendations for effective usage of sticky traps

4.1 Synopsis

Birch leaf miners easily locate birch surrounded by nonhost trees or isolated by large distances in urban neighborhoods. Therefore, for an urban pest management plan to work against these pests, it must reduce the number of immigrants. I investigated several aspects of sticky traps that affect capture of birch leaf miner adults: colour, trap material (cardboard or plastic), position in the tree canopy and the use of hexanol as an attractant. Yellow traps are attractive to both *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow). There are no significant differences between catches on plastic and cardboard traps, however plastic traps are easier to handle and would likely be preferred by homeowners. To maximize catch of *F. pusilla*, traps should be placed in areas of new growth on the canopy periphery and, to catch *P. thomsoni*, traps can be placed throughout the tree canopy and trunk. Hexanol does not attract *F. pusilla* and its influence on *P. thomsoni* is unclear.

4.2 Introduction

Understanding movement patterns of insect pests is important for making pest management decisions in both agricultural and urban settings (Horn 1988; Hart, Hall and Hanna 1991). Efficient management plans must contend with immigrants as well as movement within localized populations. For example, Hart, Hall and Hanna (1991) studied dispersal of the European alder leaf miner, *Fenusa dohrnii* (Tischbein), so that practical planting distances of new stands from infested areas could be projected.

When immigrants significantly contribute to damage, controls are used to reduce their numbers. Trapping is often effective in reducing populations of flying insects. A successful trapping program is dependent on appropriate trap placement and design that takes into account factors such as trap colour and shape, trapping medium (e.g. liquid, sticky material, pesticides) and presence of baits (Finch 1980). Anderbrant et al. (1989) demonstrated the importance of trap type, colour and position on catch of pine sawfly, *Neodiprion sertifer*, and Van Steenwyk et al. (1990) illustrated that trap position significantly affects catch rate of *Colladonus montanus* and *Fieberiella florii* (Homoptera: Cicadellidae). Trap efficiency may also be improved by adding baits such as green leaf volatiles which have been shown to act as host plant attractants (Dickens et al. 1990). Hexanol is one such volatile that occurs widely in the plant kingdom and has been shown to attract insects in several orders, either on its own (Katsoyannos and Guerin 1984; Kostal 1992) or in combination with other chemicals (Dickens 1989; Robacker et al. 1990).

Two introduced species of birch leaf mining sawflies, *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow) create unsightly leaf mines on ornamental birches in Alberta. Control measures used to reduce resident leaf miners on individual trees might be compromised by immigrant adults from uncontrolled areas. This is an important consideration in urban settings since an uncontrolled area can be as close as a neighbor's birch tree. Consequently, it is important to understand dispersal patterns of adult leaf miners.

I investigated how far adults can disperse and if their movement is restricted by patchy distribution of birches in urban neighborhoods. Since sticky traps are readily available to homeowners for pest control, I studied several aspects of sticky traps that might affect catch of adult birch leaf miners: colour, trap material (cardboard or plastic), position in tree canopy and use of an attractant (1-hexanol).

4.3 Materials and Methods

4.3.1 Movement of adult birch leaf miners

Two experiments were run in 1994 to study dispersal distance and patterns of adult birch leaf miners. The first was set up on the University of Alberta campus. Landscape fabric and gravel were placed under three trees to prevent emergence of resident adult birch leaf miners. Consequently, all birch leaf miners trapped on these trees were immigrants from untreated birch trees. The three trees differed in their proximity to untreated birch trees, either 6, 25 or 75m. Four yellow sticky traps were placed on the outer edges of the lower canopy in each tree, one in each cardinal direction. All traps were changed weekly from May 17th to August 9th and the numbers of *F. pusilla* and *P. thomsoni* were tallied.

The second experiment, a mark-release-recapture, was run over five consecutive, sunny days (July 19-23, 1994) on four acreages located within the City of Edmonton (maximum daily temperatures ranged from 24 to 28°C [Environment Canada 1994]). On these acreages, birch trees were separated by distances of 2 - 125m and some trees were separated by a stand of spruce and a farm yard about 40m wide. Sixty-eight sticky traps were placed in birch spread over four acreages. One central birch was used as the release tree on each of the three release days, July 19th, 20th and 21st. Distances of each trap from the release tree were measured (ranged from 0 to 288m). Adult sawflies were captured with aspirators from a site with a large population of *P. thomsoni* and transported to the release site. Immediately before the adults were released, they were marked with Day-Glo®, a fine, nontoxic, fluorescent powder. A different colour was used on each release day, orange, pink and green respectively. A total of 1230 adults were released. Traps were removed on July 23rd and examined for marked adults.

4.3.2 Trap colour

In July of 1993, I investigated the response of *P. thomsoni* adults to white, bright yellow and super yellow (green-yellow) traps. One trap of each colour was placed at least 75cm apart in the lower crown of each of 11 trees, one to two metres from the ground depending on size of tree. After seven days, I removed the traps and counted adult birch leaf miners.

4.3.3 Trap material

Both cardboard and plastic sticky traps are commercially available but plastic traps are easier to label and handle and are thus more convenient. However, convenience should not be the sole criterion influencing trap choice. It is also important to ascertain how these two traps types compare with respect to their effectiveness at trapping birch leaf miners and a parasitoid that attacks *P. thomsoni* larvae, *Lathrolestes luteolator* (Gravenhorst) (Chapter 3).

Two experiments were established to compare adult birch leaf miner catches between yellow plastic and cardboard sticky traps (Chroma-Line Card Traps from Phero Tech Inc.). The first experiment was run over 12 days (July 6-18, 1994) on the University of Alberta campus. In each of five birch trees, I placed one plastic and one cardboard trap in the lower crown about 30 cm apart. After 12 days, I removed the traps and counted birch leaf miner adults.

This led to a second experiment run over seven days (July 19-26, 1994) at a suburban acreage. On each of four birch, I placed two sets of traps, each set containing one plastic and one cardboard trap, on the outer edge of the lower canopy. One set was removed from each tree after three days and the second set after seven days. Birch leaf miner adults and *L. luteolator* adults were tallied.

4.3.4 Trap position

I investigated the effect of trap position on catch of *F. pusilla* and *P. thomsoni* on three small (~6m tall) and three large (~10m) birch trees on the University of Alberta campus. Eight traps were placed on the south side of each tree as follows (Figure 4-1): Trap 1 on ground midway between trunk and dripline; Trap 2 on trunk, midway from ground to lower canopy; Trap 3 on lower edge of canopy near the trunk; Trap 4 on lower edge of canopy midway between trunk and outer edge of canopy; Trap 5 on outer edge of canopy, 2.0m (small trees) or 2.3m (large trees) from the ground; Trap 6 on outer edge of canopy, 3.1m (small trees) or 4.6m (large trees) from the ground; Trap 7 on outer edge of canopy, 4.7m (small trees) or 5.9m (large trees) from the ground; Trap 8 on outer edge of canopy, 6.0m (small trees) or 7.8m (large trees) from the ground. Traps 1, 5, 6, 7 and 8 were used for vertical comparisons and traps 2, 3, 4 and 5 for horizontal comparisons. Traps were set up from May 25th to June 1st, 1994 to catch *F. pusilla* and from June 30th to July 7th, 1994 to catch *P. thomsoni*.

4.3.5 Hexanol baits

I ran experiments in both 1994 and 1995 to determine if 1-hexanol increased the attractiveness of sticky traps to *F. pusilla* and *P. thomsoni* adults. In 1994, I ran an experiment during the *F. pusilla* emergence period (June 9th to 13th) and again during the *P. thomsoni* emergence period (July 15th to 19th) at an acreage site on the outskirts of Edmonton. One yellow sticky trap was placed in each of 15 trees. Of the 15 traps, three traps were unbaited and four groups of three were each baited with one of four different concentrations of hexanol, 6.25%, 12.5%, 25% and 50%, diluted with mineral oil (1-Hexanol [98%] and Light White Mineral Oil, both from Sigma). I made containers for bait out of polypropylene microcentrifuge tubes (1.5ml capacity) by making a hole in the lid of each tube and inserting a wick made from a humidifier pad through the hole and into the solution. Tubes were attached to the lower edges of sticky traps. After four days, I removed the traps and tallied captured adults.

In 1995, I ran a follow-up experiment to test if patterns witnessed in 1994 were consistent for both *F. pusilla* and *P. thomsoni*. I chose one tree at each of seven sites. On each tree I placed a set of five traps in an open southern exposure; traps were placed 1.5 m apart on the outer edge of the tree canopy. Traps were baited as before with different concentrations of hexanol diluted with mineral oil, 6.25%, 12.5%, 25% or 50% or just 1.5 ml of mineral oil (0%). After four days (*F. pusilla*, June 8th to 12th and *P. thomsoni*, July 13th to 17th), I removed the traps and counted trapped birch leaf miner adults.

Also in 1995, I measured release rates (mg/day) of the five hexanol concentrations. During each emergence period, I used three sets of five lures. Each set contained one lure for each concentration of hexanol and one for mineral oil (0% hexanol). During *F. pusilla* emergence, I placed the lures in trees located on three of the same sites used for the baited sticky traps, and during emergence of *P. thomsoni*, I placed the lures in a sheltered location at ambient temperatures. I weighed the lures before and after the four days and calculated the mean release rate (mg/day) of each concentration of hexanol.

4.3.6 Statistical analysis

Data from experiments investigating effects of trap colour, position and attractants were analysed with SAS, general linear models procedure (SAS Institute 1988). ANOVA (α=0.05) was used to determine if significant differences existed between treatments and specific pairwise comparisons were made with *a-posteriori* t-tests (α=0.05) using least squared means. Two-tailed, paired t-tests were used to analyse differences between cardboard and plastic traps.

4.4 Results

4.4.1 Movement of adult birch leaf miners

When local recruitment was suppressed, the tree furthest from other birches attracted the fewest birch leaf miners of both species (Figure 4-2). Numbers fell more quickly for *F. pusilla* as distance between treated and untreated trees increased.

In the mark-release-recapture experiment, 41 of the 1230 *P. thomsoni* released were trapped for a recapture rate of 3%. The number of adults recaptured decreased exponentially with distance from the release tree (Figure 4-3). The farthest a marked adult was captured from the release tree was 129m which was traveled in two days. Other marked adults were trapped on trees radiating in all directions from the release tree. This means birch leaf miners do not stop at the nearest tree and that they are capable of locating birch on the other side of nonhost tree stands and open fields.

4.4.2 Trap colour

There were significant differences between catch rates on different coloured traps ($F=9.66$, d.f.=2, 20, $p=0.0012$). *A-posteriori* t-tests showed that catch on white traps was significantly lower than on the bright yellow ($p=0.0013$) and super yellow traps ($p=0.0009$) (Table 4-1).

4.4.3 Trap material

Differences between catches on plastic and cardboard traps after 12 days was marginally insignificant (Table 4-2). Catches on plastic and cardboard after three and seven days were also insignificantly different. Although the means of trapped leaf miners were similar between the three day plastic and cardboard traps, the means from the seven day traps were further apart (Table 4-2). While statistical evidence does not support differences between the two trap materials, there is a favorable trend towards cardboard.

4.4.4 Trap position

Data on capture of *F. pusilla* collected from the line of horizontal traps (positions 2, 3, 4, 5) was not normally distributed and was transformed using log10+1. ANOVA showed that trap position significantly affected catch rate (Table 4-3A). *A-posteriori* t-tests showed that traps on the outer edges of birch canopies (position 5) captured significantly more *F. pusilla* adults than those within canopies on both large and small trees (Table 4-4a). For *P. thomsoni*, (Table 4-4b), ANOVA showed no significant differences existed among traps in the horizontal line (Table 4-3B). There were no significant differences between traps in the vertical line (Table 4-3C and D) for either species (Tables 4-5a and b); however there is a tendency for *F. pusilla* to aggregate at edges of lower canopies and at the tops of crowns as seen on large trees but not small (Table 4-5a). There was a significant size effect in three of the four comparisons (Table 4-3) since traps on large trees caught more birch leaf miners.

4.4.5 Hexonal baits

During *F. pusilla* emergence, when lures (set 1) were placed in trees, strong gusts of wind spilled some lures, thus release rates were calculated for only unspilled lures. No lures were lost in set 2. In general, release rates increased with hexanol concentration (Table 4-6), however, in set 2 the means were very similar for the 6.25% and 12.5% concentrations.

In 1994, there was a significant effect of hexanol concentration on catches of *P. thomsoni* (F=4.33, d.f.=2, 8, p=0.0372). *A-posteriori* t-tests showed no difference in captures between the 12.5% and 50% concentrations, but they were significantly lower than captures at the 0% and 25% concentrations. The 6.25% concentration only differed significantly from the 12.5% concentration (Table 4-7a). Contrary to the 1994 results, hexanol concentration did not affect catch of *P. thomsoni* in 1995 (F=0.74, d.f.=4, 20, p=0.5738). However, numbers of *P. thomsoni* decreased dramatically from a total catch in 1994 of 2959 adults to 188 in 1995.

An ANOVA showed no significant effect of hexanol concentration on catches of *F. pusilla* in either 1994 (F=0.74, d.f.=4, 8, p=0.5894) or 1995 (F=0.86, d.f.=4, 20, p=0.5040) (Table 4-7b).

4.5 Discussion

4.5.1 Movement of adult birch leaf miners

Birch trees separated by distances of 25m received as many *P. thomsoni* immigrants as trees separated by only 6m, but the number of immigrants decreased markedly when trees were 75m apart (Figure 4-2b). This pattern is also apparent in the mark-release-recapture experiment where 73% of the marked *P. thomsoni* adults were caught within 30m from the release tree (Figure 4-3). This experiment also showed *P. thomsoni* adults are able to transverse distances over 125m (Figure 4-3). The catch of *F. pusilla* dropped more dramatically as distance between trees increased (Figure 4-2a). Previous work on a closely related species of sawfly, *F. dohrnii*, showed that dispersal fell of sharply at distances greater than 5m (Hart, Hall and Hanna 1991). *Fenusa pusilla*, however, is capable of transversing distances of at least 75m (Figure 4-2a).

Both species of birch leaf miner can easily locate birches surrounded by nonhost trees or isolated by large distances. Because many birch in urban neighborhoods are located less than 25m apart, it is clear that immigration is an important component in population dynamics of birch leaf miners. Therefore, an effective pest management plan must target immigrants as well as residents to achieve damage suppression.

4.5.2 Trap colour

Colour vision shapes the behaviors of many insect species and is important in host location and selection by herbivorous insects. *Chrysomela* spp. (Coleoptera) and other leaf eating species are attracted to green and yellow which reflect wavelengths within the 500-650 nm range (Chapman 1982). Many aphids can further differentiate within this range of wavelengths and can discriminate between healthy green leaves and those yellowing because of stress (Evans 1984). Some insects, such as those in the genus *Apis* (Hymenoptera), can differentiate between wavelengths differing by as little as 8 nm (Chapman 1982). Thus, colour is often important when designing a trap that is intended to attract a specific insect.

In many studies, yellow is used to attract insects of the order Hymenoptera (Hart et al. 1991; Viggiani 1991; Maier 1992; Messing and Wong 1992; Ortiz-Sanchez and Aguirre-Segura 1993; Aizen and Feinsinger 1994). Although yellow traps are attractive to *P. thomsoni*, these sawflies do not differentiate between bright yellow and super yellow traps (Table 4-1). Although *F. pusilla* adults were not specifically tested, subsequent observations established that large numbers of *F. pusilla* are also attracted to yellow traps.

The relationship between colour intensity of leaf supernatants and rate of oviposition by *F. pusilla* has been studied (Fiori and Craig 1987). Leaves that were highly susceptible to oviposition had aqueous supernatants with visible absorbance ratios 2.5 to 4-fold greater than those in resistant leaves. Future research may provide information leading to development of a very specific trap colour that will attract larger numbers of *F. pusilla*. In the meantime, researchers and property owners are not restricted to using specific yellows and can use the commercial yellow sticky traps readily available in local markets.

4.5.3 Trap material

Although differences between catches of birch leaf miners on plastic and cardboard traps are not statistically significant (Table 4-2), I would hesitate to use the plastic traps for research on birch leaf miners. I believe the lower mean catches on seven and twelve day plastic traps can be attributed to glue which seems to dry faster on plastic traps. Not only does efficiency of plastic traps decrease over time because of dry glue, the birch leaf miner adults already caught on the traps haphazardly fall off (personal observation). This would explain why catches on two trap types are similar after three days but after seven and twelve days, there are larger differences between the means (Table 4-2). If large numbers of adults fall off, differences in catches between trees would be distorted and experimental results affected. However, one advantage of plastic traps is that they are easier to handle, and therefore may be more appropriate for homeowners to use in a pest management plan, with the stipulation that they must be changed weekly to minimize loss of effectiveness due to drying of adhesive.

The difference between catch rates of parasitoids on plastic and cardboard traps appears minimal. I suspect that since *L. luteolator* adults are not as robust as adult birch leaf miners, they do not easily fall off traps.

4.5.4 Trap position

Leaf selection for oviposition by each species of birch leaf miner foreshadowed experimental results. *Fenusa pusilla* attacks new growth (DeClerck and Shorthouse 1985; Lindquist 1959) and has been reported to prefer the upper crown (Drouin and Wong 1984; Jones and Raske 1976), although one study indicated there is even distribution between upper and lower crowns (DeClerck 1984). In contrast to *F. pusilla*, *P. thomsoni* attacks mature leaves and, although it seems to prefer leaves in the lower canopy, it will attack all areas of the crown in heavy infestations (Martin 1960). As anticipated, experiments showed that traps placed in areas of new growth catch the most *F. pusilla* adults whereas *P. thomsoni* is more evenly distributed throughout the tree. To maximize catch of *F. pusilla*, traps should be placed in areas of new growth on the canopy periphery starting on the lower edge and moving up. Since trap position has less influence on catch of *P. thomsoni*, traps can be placed throughout the canopy and on the trunk.

4.5.5 Hexanol baits

Results indicate that hexanol does not attract *F. pusilla* and that the affect on *P. thomsoni* is unclear. Results from 1995 show no attraction of hexanol to *P. thomsoni* but significant differences may be obscured because of low numbers. Significant differences between catch rates of *P. thomsoni* in 1994 are questionable because hexanol concentrations were not reflected by release rates. In data from 1994, significant differences existed between catch rates of *P. thomsoni* on the 6.25% and 12.5% hexanol baited traps but when release rates were measured in 1995, these two concentrations were almost identical (Table 4-6).

Environmental factors affect catch rate and may have contributed to the contradictory results. For instance, Tigar et al. (1993) reported that, over short time scales, rainfall, temperature and wind appeared to influence catch rates of *Prostephanus truncatus* (Coleoptera: Bostrichidae) on pheromone baited traps. Strong winds, for example, break up the pheromone plume making it more difficult for insects to follow. Not only would wind disrupt hexanol trails, it apparently increased evaporation rate. Lures placed in trees exposed to strong winds released more hexanol then the second set kept in a sheltered location (Table 4-6). It is difficult to compare attractiveness of different hexanol concentrations under these circumstances and future studies will want to address these obstacles and standardize chemical release rates. Commercially made lures, although expensive, may reduce the problem of variation between release rates. A second alternative would be to use the same concentration of hexanol in each vial and increase release rate by increasing the number of vials attached to each trap.

It is logical that *P. thomsoni*, a parthenogenetic species, is attracted to a host plant by chemicals in the plant instead of by pheromones which might attract sexually reproducing species like *F. pusilla*. Birch leaf phenolics tend to increase over the growing season (Haukioja and Niemelä 1979) and since *P. thomsoni* attacks mature leaves later in summer, it is possible that they use phenolics to identify older leaves. Many phytophagous insects are attracted to a complex of general green leaf volatiles. The relative proportion of each volatile in the mixture identifies a specific host plant (Visser and Avé 1978). *Profenusa thomsoni* females apparently do not discriminate between leaves for oviposition and instead may choose an entire tree rather than specific leaves (Digweed 1995). There may be a certain combination of volatiles that identify a tree as being optimally suitable for oviposition. However, other factors may help determine suitability. Fiori and Craig (1987) demonstrated that resistance of *Betula davurica* to *F. pusilla* may be due to colour intensity of leaf supernatants. More research is necessary to determine what characteristics, volatile or otherwise, *P. thomsoni* females use to identify a suitable host tree for oviposition.

4.5.6 Recommendations for effective usage of sticky traps

More research is needed to determine the minimum number of traps required on a tree to achieve acceptable levels of aesthetic damage. Aesthetic damage levels are appropriate to judge success of control procedures since homeowners use these trees for ornamental purposes. Accordingly, this research should be done in areas with high levels of miner damage (e.g. Slave Lake, Chapter 3) so that aesthetic damage levels can be assessed. The parasitoid, *Lathrolestes luteolator*, has caused a drastic reduction of the Edmonton population of *P. thomsoni* and aesthetic damage levels are now very low on both treated and untreated trees, making it difficult to appraise control procedures.

I recommend that the City of Edmonton, Forestry and Environmental Service use yellow sticky traps to monitor populations of *P. thomsoni* and its parasitoid *L. luteolator* so that if the leaf miner population starts to increase, appropriate measures can be taken to avoid high levels of damage on ornamental birches. City pest management services could also monitor for two other introduced species of birch leaf miner, *Messa nana* (Klug) and *Scolioneura betuleti* (Klug), that are presently in eastern North America (Goulet 1992), but might eventually move westward. Both have associated parasitoids (*Lathrolestes* sp.) (Pschorn-Walcher and Altenhofer 1989) that could possibly be imported if these species of birch leaf miners are discovered. Early detection and parasitoid importation may prevent these species from causing high levels of damage.

Recently, a specialist parasitoid of *F. pusilla*, *Lathrolestes nigricollis*, was introduced to Edmonton (Digweed, Langor and Spence, unpublished) and progress of this parasitoid should also be monitored. Until effects of this parasitoid are known, sticky traps would be useful on young and/or newly-transplanted birches that are susceptible to attack by *F. pusilla* because of large amounts of new growth available for oviposition throughout these trees. Homeowners should place yellow, plastic sticky traps on the periphery of their young birch trees, from the lower to upper crown. Additional measures must also be taken to control resident birch leaf miners under the tree (Chapter 2).

One final important benefit of sticky traps is their role in public education. Sticky traps are important educational tools in that they allow homeowners to see the pest attacking their trees. This increases people's awareness and provides an opportunity for them to get more involved in integrated pest management (Ball 1986).

Table 4-1. Mean (±SE) numbers of *P. thomsoni* adults trapped on white, bright yellow and super yellow sticky traps. One trap of each colour was placed in each of 11 trees. Means followed by the same letter are not significantly different.

Trap colour	bright yellow	super yellow	white
	191 ± 37.0 a	198 ± 68.4 a	13 ± 3.6 b

Table 4-2. Mean (±SE) number of birch leaf miners caught on plastic and cardboard sticky traps over 3, 7 and 12 day periods, the mean (±SE) number of parasitoids (*L. luteolator*) caught on 3 and 7 day traps and results of two tailed paired t-tests (α=0.05) showing comparisons among trap type.

number of days	3 (n=4)		7 (n=4)		12 (n=5)	
trap type	plastic	cardboard	plastic	cardboard	plastic	cardboard
birch leaf miners	103 ± 29.5	96 ± 23.5	234 ± 54.1	305 ± 56.0	45.2 ± 15.9	76.2 ± 25.2
	(t=-0.283, d.f.=3, p=0.7955)		(t=1.051, d.f.=3, p=0.3706)		(t=2.721, d.f.=4, p=0.053)	
parasitoids	209 ± 24.8	167 ± 77.6	158 ± 49.5	162 ± 52.6	-	-
	(t=-0.675, d.f.=3, p=0.5479)		(t=0.082, d.f.=3, p=0.9397)			

Table 4-3. Analyses of variance evaluating numbers of adult birch leaf miners on sticky traps in different positions on two sizes of birch trees. A, capture of *F. pusilla* on horizontal traps (log10+1 transformed); B, capture of *P. thomsoni* on horizontal traps; C, capture of *F. pusilla* on vertical traps; D, capture of P. *thomsoni* on vertical traps.

A.

Source	df	MS	F	p
Size	1	0.23	3.76	0.0763
Tree(Size)	4	0.12	1.91	0.1727
Position	3	0.81	12.78	0.0005
Size x Position	3	0.20	3.08	0.0684
Error	12	0.06		

B.

Source	df	MS	F	p
Size	1	88.17	15.45	0.0020
Tree(Size)	4	8.54	1.50	0.2644
Position	3	9.67	1.69	0.2212
Size x Position	3	12.50	2.19	0.1421
Error	12	5.71		

C.

Source	df	MS	F	p
Size	1	842.70	25.34	0.0001
Tree(Size)	4	401.00	12.06	0.0001
Position	4	95.87	2.88	0.0566
Size x Position	4	60.03	1.81	0.1771
Error	16	33.25		

D.

Source	df	MS	F	p
Size	1	70.53	6.20	0.0241
Tree(Size)	4	18.33	1.61	0.2197
Position	4	13.88	1.22	0.3410
Size x Position	4	22.62	1.99	0.1449
Error	16	11.38		

Table 4-4. Mean (±SE) number of *F. pusilla* (a) and *P. thomsoni* (b) caught along a horizontal line of traps (positions 2, 3, 4 and 5) in three small and three large birch trees. Means followed by the same letter are not significantly different. Refer to Figure 4-1 for trap position designations.

a.

	Mean of *F. pusilla*	
Trap position	small trees	large trees
2 (trunk)	0.3 ± 0.33 a	0.7 ± 0.67 a
3 (inner)	0.0 ± 0.00 a	0.0 ± 0.00 a
4 (middle)	0.3 ± 0.33 a	0.3 ± 0.33 a
5 (outer)	3.3 ± 2.85 b	20.3 ± 12.86 b

b.

	Mean of *P. thomsoni*	
Trap position	small trees	large trees
2 (trunk)	3.3 ± 1.76 a	4.7 ± 0.88 a
3 (inner)	1.7 ± 0.33 a	8.0 ± 1.53 a
4 (middle)	1.3 ± 0.67 a	2.7 ± 1.20 a
5 (outer)	1.3 ± 0.88 a	7.7 ± 2.85 a

Table 4-5. Mean (±SE) number of *F. pusilla* (a) and *P. thomsoni* (b) caught along a vertical line of traps [positions 1 (ground), 5, 6, 7 and 8 (upper crown)] in three small and three large birch trees. Means followed by the same letter are not significantly different. Refer to Figure 4-1 for trap position designations.

a.

	Mean of *F. pusilla*	
Trap position	small trees	large trees
1	0.7 ± 0.33 a	6.7 ± 2.91 a
5	3.3 ± 2.85 a	20.3 ± 12.86 a
6	2.7 ± 2.19 a	9.3 ± 6.88 a
7	6.0 ± 3.51 a	11.3 ± 5.36 a
8	4.3 ± 2.40 a	22.3 ± 8.65 a

b.

	Mean of *P. thomsoni*	
Trap position	small trees	large trees
1	1.3 ± 0.67 a	3.3 ± 0.67 a
5	1.3 ± 0.88 a	7.7 ± 2.85 a
6	6.0 ± 2.52 a	3.7 ± 0.33 a
7	4.7 ± 0.33 a	6.7 ±2.85 a
8	2.7 ± 0.88 a	10.0 ± 4.16 a

Table 4-6. Mean (±SE) release rates (mg/day) of different concentrations of hexanol. Set 1 (June 8th-12th) was placed in trees and strong winds caused many lures to spill. The number of lures still usable is noted for each concentration. Set 2 (July 12th -17th) was placed in a more sheltered location that was subject to ambient temperatures.

Concentration (%)	Set 1 rates (mg/day)	Set 2 rates (mg/day) n=3
0	1.5 (n=1)	0.3 ± 0.14
6.25	7.2 ± 0.58 (n=3)	4.0 ± 0.66
12.5	8.5 (n=1)	3.9 ± 0.73
25	17.9 ± 1.38 (n=2)	8.8 ± 0.25
50	37.3 (n=1)	26.3 ± 0.95

Table 4-7. Mean (±SE) number of *P. thomsoni* (a) and *F. pusilla* (b) adults captured on sticky traps baited with different concentrations of hexanol. Means followed by the same letter are not significantly different.

a.

1-Hexanol concentration (%)	1994 mean captures of *P. thomsoni* n=3	1995 mean captures of *P. thomsoni* n=6
0	282 ± 121.0 a	6 ± 3.3 a
6.25	230 ± 122.1 ab	7 ± 3.0 a
12.5	83 ± 28.2 c	4 ± 2.0 a
25	269 ± 96.9 a	8 ± 4.5 a
50	122 ± 61.2 bc	7 ± 4.3 a

b.

1-Hexanol concentration (%)	1994 mean captures of *F. pusilla* (n=3)	1995 mean captures of *F. pusilla* (n=6)
0	5 ± 1.2 a	23 ± 16.6 a
6.25	17 ± 6.5 a	9 ± 4.0 a
12.5	28 ± 22.0 a	30 ± 22.6 a
25	10 ± 9.8 a	28 ± 18.8 a
50	7 ± 3.8 a	9 ± 6.9 a

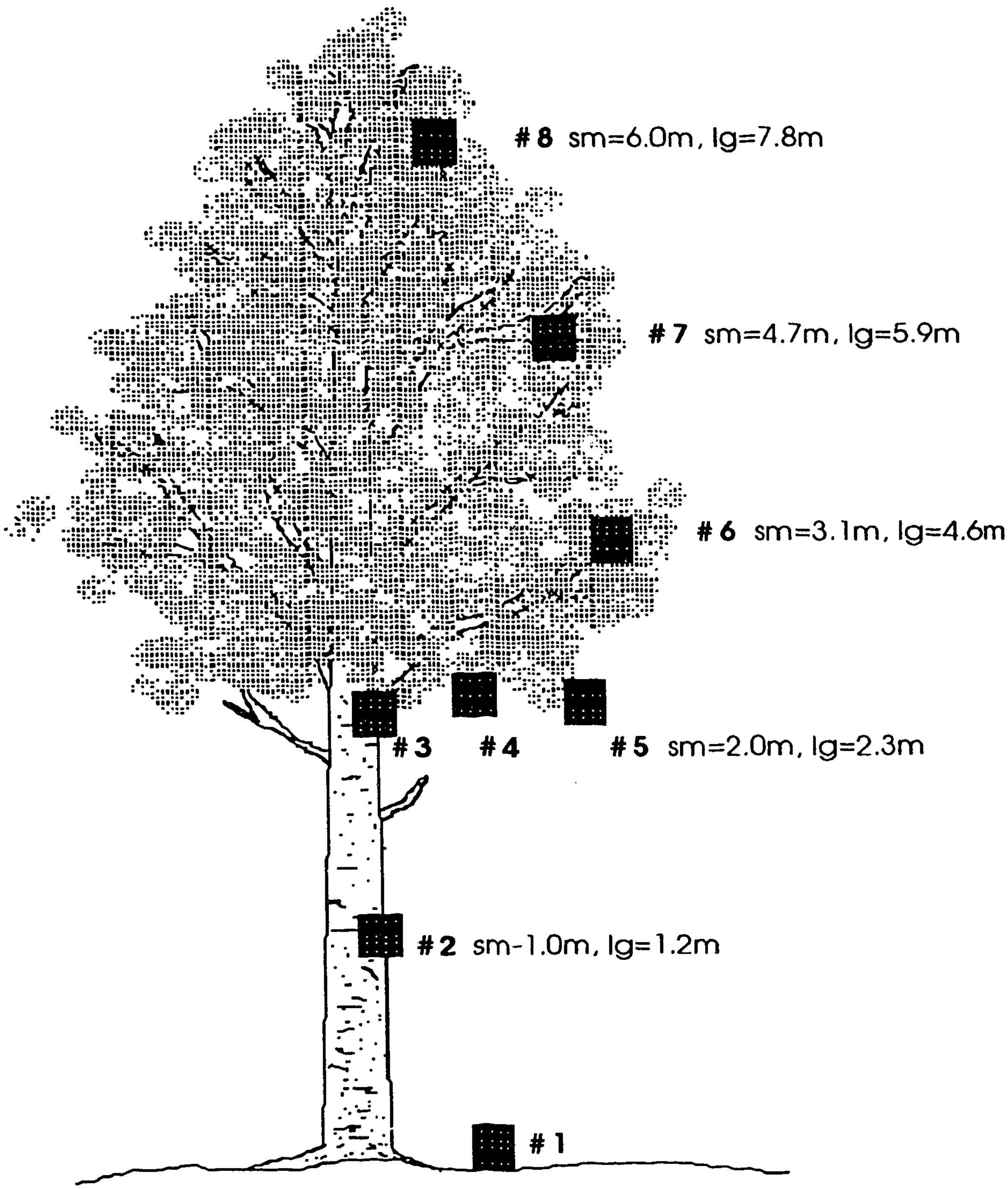

Figure 4-1. Position of sticky traps and their average distances from the ground in small and large birch trees.

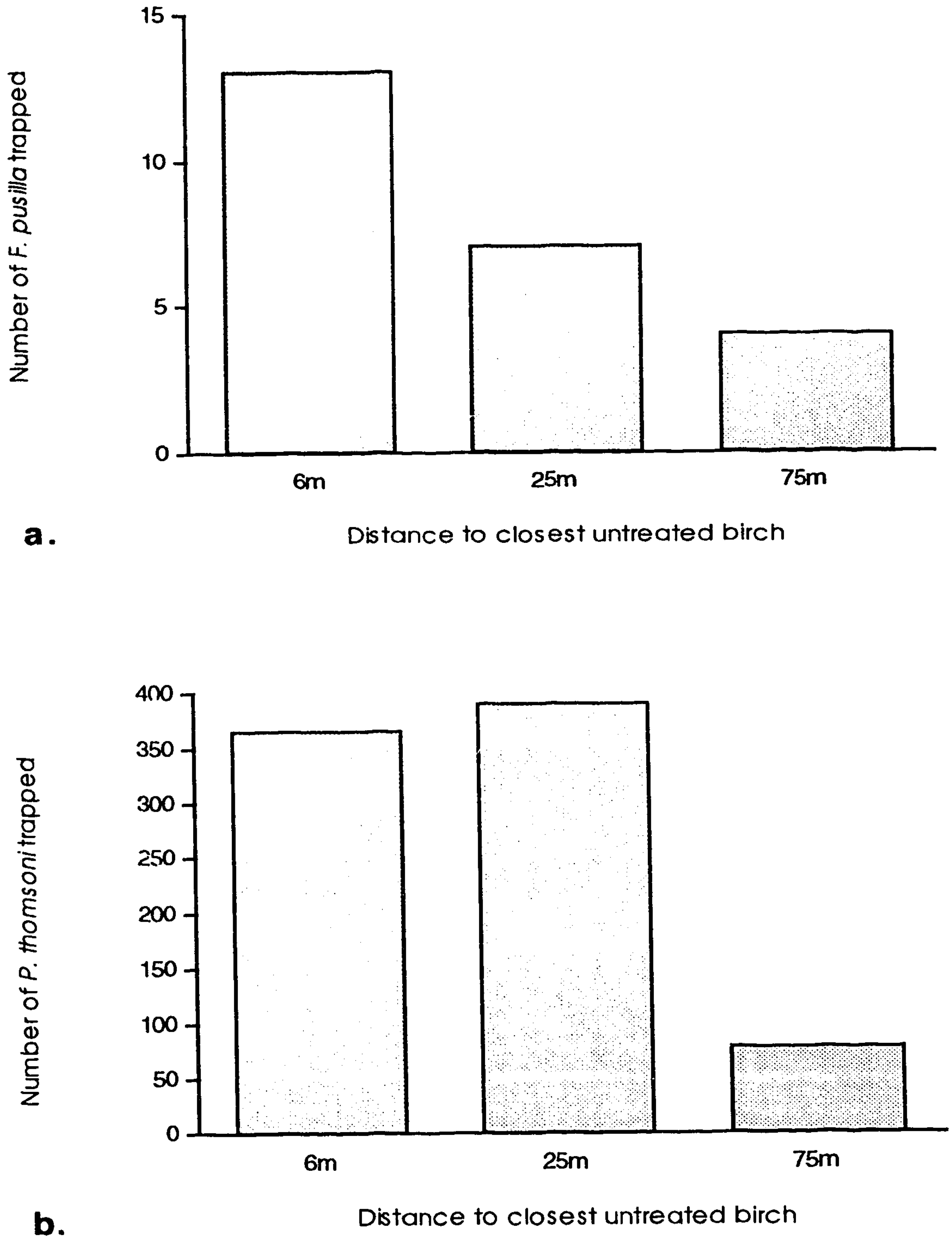

Figure 4-2. Number of *F. pusilla* (a) and *P. thomsoni* (b) captured with yellow sticky traps on birch trees with no local recruitment from May to August 1994.

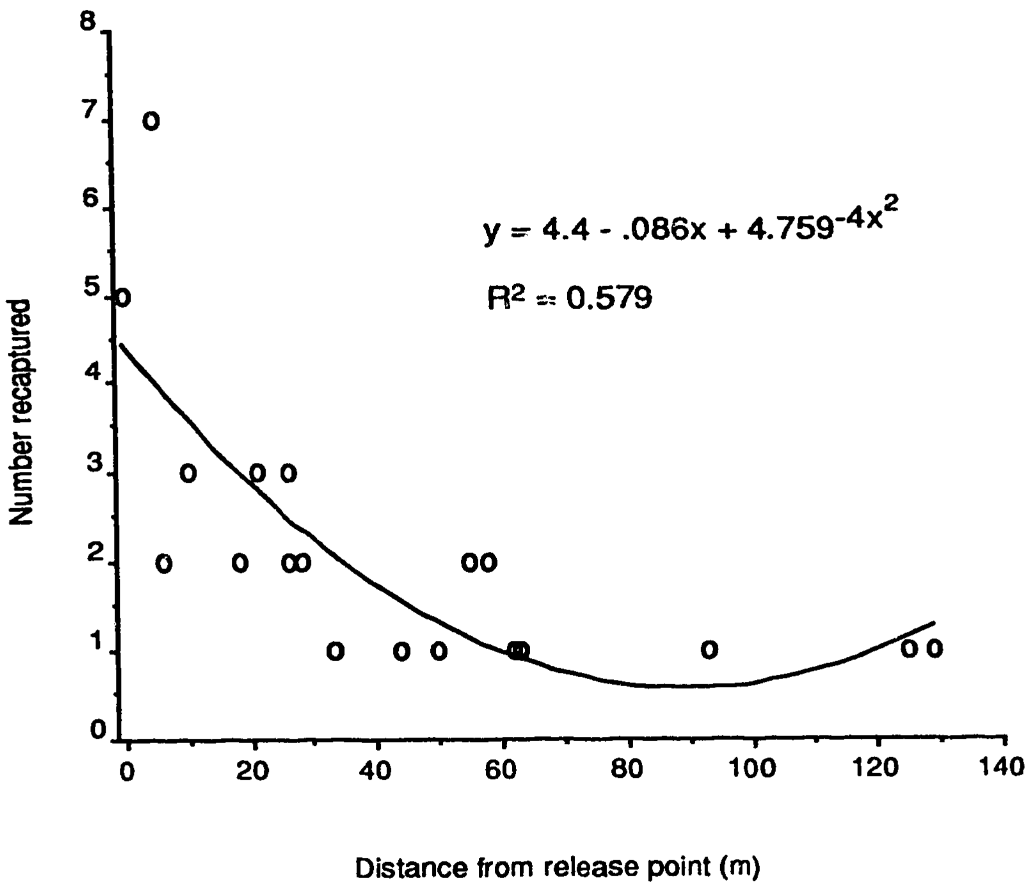

Figure 4-3. Distance travelled by marked *P. thomsoni* adults. Forty-one of the 1230 adults released were trapped for a recapture rate of 3%.

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5. Conclusion: Public Opinion and Recommendations for Pest Management of Birch Leaf Miners in Urban Settings

5.1 Dimethoate and its use in urban environments

After World War II, people started to rely on routine application of insecticides rather than on cultural and biological methods to maintain healthy trees (Nielsen 1983). Organophosphate insecticides were first used as weapons during the second world war but were then adapted for use in pest control. The insecticide commonly recommended for control of birch leaf mining sawflies, *Fenusa pusilla* (Lepeletier) and *Profenusa thomsoni* (Konow), is an organophosphate known as dimethoate. In 1993, dimethoate was the largest selling insecticide (by active ingredient) in Edmonton (Byrtus 1995). It is toxic to beneficial insects, birds and other wildlife (Wilson Laboratories Inc. 1993) and to humans (Brady 1974). It is also phytotoxic (Drouin and Wong 1984) and consequently, some people damage their trees by applying the insecticide inappropriately. Since widespread use of insecticides is becoming more socially unacceptable and highly regulated (Hermes et al. 1984) and costs associated with insecticide development are increasing dramatically (Nielsen 1983; Solomon and Stephenson 1991), insecticides are losing their appeal as practical, low cost solutions for pest control. Consequently, people will need to rely on alternative pest management strategies.

5.2 Public Opinion

5.2.1 Public survey

The willingness of the public to use alternative management methods is an integral part of changing urban pest management programs. Public opinion contributes to decisions made for city spray programs as well as those commissioned from private companies. In response to public demand, many pest control companies still offer prescheduled cover sprays to reduce pests instead of monitoring and target spray programs (Ball 1986). Obviously, public education is essential for change and, in my experience, is positively received.

I conducted a survey that provided information to the Edmonton public about *Lathrolestes luteolator* (Gravenhorst), a newly discovered parasitoid that attacks and effectively reduces populations of the birch leaf miner species, *P. thomsoni.* In light of the news about the parasitoid, I asked for feedback about people's views of insecticide use against birch leaf miners.

5.2.2 Methods

In August 1995, surveys (Appendix 1) were randomly delivered to 600 homes (no apartments), 100 in each of Edmonton's six wards. The package included an introductory letter and instructions, an information sheet about birch leaf miners and their parasitoids, and a set of questions. To determine if people could recognize birch leaf miner damage, I also included a small plastic bag and requested that people return a damaged leaf with their survey.

5.2.3 Results and Discussion

A total of 106 surveys (17.7%) were returned but nine were discarded because of unanswered questions. More than half (57.7%) of the respondents had at least one birch on their property (Table 5-1) and of those, 41.1% used insecticides in 1994 or 1995. One household hired a commercial pesticide applicator, all others did the application themselves. Cygon 2E® (dimethoate) was most commonly used (77.2%) and homeowners either applied it as a soil drench (70.6%) or painted the bark (29.4%).

Many homeowners (75.0%) had noticed a decrease in birch leaf miner damage on their own trees in the last two years, and 89.3% (including those previously not using insecticides) would refrain from using insecticides on their trees (Table 5.1) in light of information about *L. luteolator*. Over 90% of the public supported a decrease in the amount of insecticides used against birch leaf miners on city owned trees. This reflects changing attitudes in society and illustrates the need for alternatives to insecticides. Reasons cited for wanting a decrease in pesticide application included concern for the environment, personal health problems, and the dislike of insecticides such as Cygon 2E® because of smell, expense and inconsistent results.

A need for further education was evident from comments returned with surveys. Several people thought all insecticides should be banned, an idealistic and sometimes impractical solution. Integrated pest management supports alternatives to insecticides but when these are infeasible, it instead focuses on reducing volume and maximizing efficiency of insecticides. Education about integrated pest management should also provide information on recognition of damage and pest biology. Although many people can recognize damage caused by birch leaf miner, (39.6% of returned surveys included leaf samples of which 76.2% were damaged), my interactions with the public indicated that many people do not realize damage is caused by larvae feeding on inner leaf tissue. Once people realize that larvae of *P. thomsoni* and *F. pusilla* feed inside protective leaf mines, they then recognize how wasteful it is to spray contact insecticides. In the survey, 9.1% of respondents who used insecticides sprayed their trees with the contact insecticide, Malathion® for leaf miner control, a completely ineffective tactic.

In Maryland, USA, pilot integrated pest management programs for homeowners were implemented and survey results indicated these programs were successful (Smith and Raupp 1986; Holmes and Davidson 1984; Raupp and Noland 1984). Holmes and Davidson (1984) reported that many clients enjoyed learning how to recognize insects in their yards. My survey indicates that people living in the City of Edmonton are also ready to learn about insects and accept integrated pest management programs. Field guides and pest leaflets from Forestry Canada and the City of Edmonton, Forestry and Environmental Service, provide information about a variety of pests and their natural enemies. Many information services are updating their material to include suggestions for integrated pest management.

5.3 Management of Birch Leaf Miners in Urban Settings

Much of the information presented in Chapters 2, 3 and 4 contributes to a pest management program for birch leaf miners in urban areas. Effective controls are often applied to vulnerable life stages of pests. Birch leaf miner larvae are most vulnerable when attempting to enter soil where they build protective cocoons and overwinter. To prevent birch leaf miner larvae from reaching suitable overwintering sites under urban birch trees, sod should be replaced with weed mat overlaid with a layer of course, clean gravel less than 5 cm in depth. Weed mat will degrade in ultraviolet light, therefore the gravel must cover it completely. Gravel must be kept as clean as possible, otherwise larvae will have enough substrate to build cocoons thereby compromising the effectiveness of treatment. Cleanliness may be facilitated by keeping the gravel as shallow as possible and using a leaf blower to remove debris. This type of control would meld well with the use of ecoscape residential landscapes encouraged by the City of Edmonton, Public Works Department. Ecoscapes are designed to conserve water by reducing lawn and replacing it with plants and other elements that require limited water. However, while this may reduce water competition, birch trees still need ample watering since they are adapted to moist, cool forest soils (Hermes et al. 1984; Nielsen 1975). If the necessary water is not available to maintain tree health, as is often the case in urban settings, birch should be avoided as ornamentals. It is important to keep trees healthy and vigorous since they are able to withstand attack and do not suffer as much reduced growth as unhealthy trees (Paine et al. 1993; Langor et al. 1994).

Predators such as ants can easily forage on weed mat covered with coarse gravel and prey upon vulnerable larvae. Ants are important predators of birch leaf miner larvae in leaf mines (Pezzolesi and Hager 1994; Digweed 1995) and on the soil surface (Chapter 3). Ants of the genera *Formica* and/or *Camponotus* have potential as biological control agents for several pests (Beattie 1985; Youngs 1983), including gypsy moth, *Lymantria dispar* L. (Weseloh 1995) and western spruce budworm, *Choristoneura occidentalis* Freeman (Campbell and Torgersen 1982). Laine and Niemelä (1980) reported that during an *Oporinia autumnata* (Lepidoptera, Geometridae) outbreak, small green islands of mountain birch (*Betula pubescens* spp. *tortuosa*) existed around ant mounds. However, in areas outside of forests, there are restrictions in the use of ants for biological control, especially in man-made vegetation where plant, predator and parasitoid diversity is low (Beattie 1985). Ants drive away other predators such as coccinellid beetles and syrphid flies and they also tend aphids. This often results in damaging population explosions of plant feeding homopterans. Consequently, I do not recommend augmentation of ants in urban areas for management of birch leaf miners since this may replace one pest problem with another. Nonetheless, while increasing ant populations in cities is not feasible, increased tolerance of ants should be emphasized in pest management programs. Many homeowners do not realize the important roles ants fulfill in ecosystems; ants are both predators and scavengers, and they help improve soil quality (Brian 1977). However, distinctions must be made between ant species so that homeowners can recognize harmful species such as carpenter ants (*Camponotus* spp.).

Birch leaf miner adults easily locate birch that are surrounded by nonhost trees or isolated by large distances in urban neighborhoods (Chapter 4). Therefore, for an urban pest management plan to be effective, it must reduce immigrants. To capture *F. pusilla* adults from uncontrolled areas, homeowners should place yellow, plastic sticky traps on the periphery of birch canopies in areas of new growth, from the lower to upper crown. Traps to capture *P. thomsoni* can be placed throughout the tree canopy and on the trunk. Sticky traps are only necessary during periods of adult activity, mid-May to June and again in July for *F. pusilla*, and July to mid-August for *P. thomsoni* (Digweed 1995). More research is needed to determine the proportion of damage caused by immigrants and the minimum number of traps required to achieve acceptable levels of aesthetic damage (Chapter 4). Sticky traps can also be used as educational tools in that they allow homeowners to see which pests are attacking their trees. This increases people's awareness and provides an opportunity for them to get more involved in integrated pest management (Ball 1986).

Birch leaf miner control has been greatly improved in Edmonton by the parasitoid, *Lathrolestes luteolator* (Chapter 3). In 1994, this parasitoid was discovered attacking the most damaging species of birch leaf miner in Alberta, *P. thomsoni*. This discovery coincided with a drastic reduction in *P. thomsoni* populations in Edmonton. To maintain low damage levels, I recommend that City of Edmonton, Forestry and Environmental Service use sticky traps to monitor populations of *P. thomsoni* and *L. luteolator* so that if the leaf miner population starts to increase, appropriate measures can be taken to avoid high levels of damage on ornamental birches.

A specialist parasitoid of *F. pusilla, Lathrolestes nigricollis* (Thomson), was recently released at two sites in the City of Edmonton and is apparently established at one site (Digweed, S., pers. comm.). Sticky traps should also be used to monitor the progress of *L. nigricollis*. Until this parasitoid is widely established and effectively controlling populations of *F. pusilla*, I recommend using the previously mentioned, nonchemical management methods on young and/or newly transplanted birch. Homeowners are more aware of aesthetic damage from *F. pusilla* on young, small trees since damage is visible throughout canopies. On large trees, damage is concentrated on new growth high in the tree canopy and is not as noticable. Also, limiting treatment to small trees will also lessen the impact of control on *L. luteolator*.

Finally, I recommend that the City of Edmonton monitor for two other introduced species of birch leaf miner, *Messa nana* (Klug) and *Scolioneura betuleti* (Klug), that are presently in eastern North America (Goulet 1992), but might eventually move westward. Both have associated parasitoids (*Lathrolestes* sp.) (Pschorn-Walcher and Altenhofer 1989) that could possibly be imported if these species of birch leaf miners are discovered. Early detection and parasitoid importation may prevent these species from causing high levels of damage.

The concept of integrated pest management was originally developed for use in agriculture and forestry where productivity builds the foundation for management decisions. The economic injury level (EIL) is used to determine when pest control is warrented (Horn 1988). Research determines the EIL by identifing what level a pest population must reach before loss of product is greater than cost of pest control. This decision-making process is not as straightforward in urban settings where aesthetic injury provides the impetus for insect control. Progress has been made in determining aesthetic injury level, (Raupp et al. 1988) but diffculties remain because the level depends on diverse public perception of damage rather than set market values and production costs. Future research into urban pest management needs to further define aesthetic injury levels for birch leaf miners and other pests so that cost effective management can be provided with consistant results. This must be coupled with efforts to increase tolerance of pest damage, perhaps by providing information about the level of damage required to seriously compromise plant health (Raupp et al. 1988). By focusing on total plant health instead of remedial measures to deal with pest problems, homeowners and professional landscapers can develop a holistic approach for maintenance of healthy, beautiful, urban landscapes (Nielsen 1983). Insects need to be recognized as only part of the many interactions in complex urban ecosystems if long term pest management is to be successful.

Table 5.1. Summary of answers from 97 respondents to a public survey conducted in Edmonton.

Did homeowners have birch on their property?	
Yes: 56 [illegible]%)	No: 41 (42.3%)
Did homeowners use insectici[illegible] their birch trees in 1994 or 1995? Yes: 23 (41.1%) No: 33 (58.9%)	-
Did homeowners notice a decrease in leaf miner damage on their birch in 1994 and 1995? Yes: 42 (75.0%) No: 14 (25.0%)	-
With the arrival of the parasitoid, would homeowners consider stopping insecticide applications on their birch? Yes: 50 (89.3%) No or Undecided: 6 (10.7%)	-
Did homeowners notice a decrease in leaf miner damage on city owned birch?	
Yes: 17 (30.4%) No: 39 (69.6%)	Yes: 5 (12.2%) No: 36 (87.8%)
Would homeowners support a decrease in the amount of insecticides used against birch leaf miner on city owned birch?	
Yes: 51 (91.1 %) No or Undecided: 5 (8.9%)	Yes: 38 (92.7 %) No or Undecided: 3 (7.3%)

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Appendix 1. Public Survey Package

Hello.

My name is Robin McQueen and I am a summer employee with the City of Edmonton and a student at the University of Alberta. I study birch leaf miners, the pests that eat the insides of birch leaves and cause them to turn brown. I would like your opinion on some exciting news in the world of birch leaf miner. A new parasite has arrived in Edmonton and it is causing a decline in the number of birch leaf miners. I would appreciate it if you would take the time to read the information sheet and then answer the following 9 questions, even if you do not have any birch on your property.

The questions primarily focus on the use of insecticides. Since these chemicals are a part of everyone's life, I want to hear your opinion. Please return your completed question sheet by September 7th, 1995 in the addressed, stamped envelope provided. There is also a small plastic bag included in this package. If you have birch leaf miner damage in your area, I would appreciate it if you could mail a damaged leaf back to me and include the name of the area in which you found it on the question sheet (e.g. the address of the building the tree is closest to).

If you have any questions, please contact me. I will be using the results of this survey in my thesis but I will not be including any names or addresses. I appreciate your help. Thank-you.

Yours truly,

Robin McQueen

City of Edmonton, Parks and Recreation
Forestry and Environmental Service
Pest Management

University of Alberta
Department of Biological Sciences

Birch leaf miners have caused extensive damage on ornamental birch since the 1970's. There are actually three species of birch leaf miner and all are originally from Europe. When they arrived in Alberta, none of the natural enemies that kept the miner population under control in Europe were here. However, it looks like this has changed.

Many people have noticed a decrease in the amount of miner damage on their birches. This decrease is not due to insecticides, but has been caused by a small parasitic wasp, *Lathrolestes luteolator*, that only attacks the most damaging species of miner larvae, the amber marked birch leaf miner (*Profenusa thomsoni*). 1994 was the first summer in which this parasitic wasp was abundant.

This year, the most visible damage was caused by the birch leaf miner, *Fenusa pusilla*. Damage caused by this species is located on the tips of branches and the top of the tree because it only attacks new growth instead of mature leaves like the amber marked birch leaf miner. Researchers at the University of Alberta have recently released a species of parasite that only attacks *Fenusa pusilla*. Hopefully this parasite will permanently establish itself in Edmonton in the next few years and reduce the numbers of *Fenusa pusilla*.

You can help beneficial insects that reduce populations of birch leaf miners. The most important thing to do is refrain from using insecticides on your birch. Weak insects are more susceptible to insecticides and this may include parasitized miner larvae. Consequently, by using an insecticide you will not only kill birch leaf miner but you will also kill the beneficial parasites as well as the predators that feed on miner larvae. It may take a couple of summers for these natural controls to reduce the birch leaf miner population in your area, but the wait is worth it in the long run. Nature may not be as quick as man-made insecticides but it is more stable and less polluting.

One other method of pest management is to ensure your tree is in good health. Birch leaf miner will not kill your tree but several heavy, consecutive infestations will weaken your tree and make it more susceptible to disease and attack by other pest insects. Help your tree stay healthy by providing water and fertilizer. If you can, remove other plants from beneath the tree that are competing with your birch for water. (This includes your lawn.)

The city will continue to monitor birch leaf miners and their parasites, and will inform the public of any more exciting discoveries.

Please answer the following questions. If you do not have birch on your property, answer questions 1,7 and 9.

1) Do you have birch on your property? How many? What is your address?

2) Have you ever treated your birch with insecticides such as Cygon 2E®? If yes, did you do the treatment or did you hire a commercial spraying service?

3) What insecticide did you use?

4) How did you apply the insecticide? (e.g. sprayed the leaves or painted the bark or used a soil drench)

5) What year did you last treat your birch?

6) Have you noticed a decrease in the amount of birch leaf miner damage on your tree in the last two years?

7) Have you noticed a decrease in the amount of birch leaf miner damage on city trees?

8) With the arrival of the new parasite, would you consider stopping insecticide applications on your birch?
If yes, why?

If no, why?

9) Would you support a decrease in the amount of insecticides used against birch leaf miner on city owned birch?

Location of enclosed leaf if applicable:

Additional comments:

Thank-you for your time.