SUBLETHAL EFFECTS OF FENITROTHION ON FOREST PASSERINES

By

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ABSTRACT

A five-year study was carried out to test a sensitive, nondestructive, new method for determining sublethal and long-term consequences of fenitrothion applications on forest songbirds. I used censuses and territory mapping of singing males to provide indices of relative abundance on sprayed and control plots. Mist-netting was used to colour-band individuals of 3 indicator species (the chestnut-sided warbler, magnolia warbler and white-throated sparrow), to determine their breeding condition, and to follow their fates after a fenitrothion application. Time-budget observations were made of the behaviour of some marked individuals. Fenitrothion was applied aerially in 1985, and by ground in 1986.

I first studied the effect of fenitrothion on the songbird community; comparing treatment and control plots, before and after the application. Data on the bird populations showed that fewer young were caught in 1985, and birds returned at a lower rate the year following treatment; a lower proportion of the 1986 catch in mist nets were males. Nonetheless, other factors (budworm cycles, for example) had a greater influence on population trends than the treatment.

Behavioural observations indicated that individuals of the 3 indicator species did not abandon the treated area after either application, although white-throated sparrows and magnolia

warblers moved away from foliage regions with higher deposits of spray. There was no significant change in the allotment of time to social, maintenance, or feeding behaviours, for any of the indicator species. This observation is not consistent with the known symptoms of organophosphate poisoning (i.e. increased time spent sitting, bill-wiping, and preening). Chestnut-sided warblers and white-throated sparrows continued to forage actively on sprayed plots or nearby. Magnolia warblers decreased their foraging effort after both applications.

In part 2 of the thesis, I studied the effect of fenitrothion on the invertebrate food of forest songbirds. Branch samples were taken as a measure of the food available to foliage-gleaning birds. Drop trays were placed under sample trees to measure the amount of food fallen from the tree after the application. Following treatment, there was a lower density of invertebrates on white birch and balsam fir branches than on control trees. This reduction was not observed until 5 days after the application, although drop tray samples indicated an immediate kill of invertebrates. These techniques sampled different types of invertebrates such that a large proportion of the drop tray samples were not associated with the tree (eg. flying Diptera). In addition to a decreased abundance, a large portion of the remaining invertebrates on white birch treated trees were dead. This suggests a further decrease in food availability to birds like warblers that specialize on moving prey.

The depression of food available to birds was probably short-lived, assuming movement of invertebrates into depopulated areas from unsprayed foliage nearby. Behavioural responses of birds to spraying were also short-lived, apparent only within 5 days of the application. At the maximum allowable single dose, fenitrothion appears to have little effect on forest songbirds, even when tested with a highly-sensitive method.

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INTRODUCTION

For 30 years, chemical spraying of spruce budworm (Choristoneura fumiferana (Clem.)) has been a fact of life in New Brunswick, and a major thrust of forest pest management in Eastern Canada as a whole. Not surprisingly, there has been concern over the environmental consequences of these practices. The research spurred by this concern has been summarized in several excellent reviews (Pearce 1971; NRCC 1975; Pearce 1975; Varty 1975; Bart and Hunter 1978; Grue et al. 1983; Peakall and Bart 1983; Peakall 1985).

Despite this volume of research, the exact effects of forestry insecticides, specifically fenitrothion, on forest songbirds still remain a mystery; as does the long-term result of their use. Nevertheless, two possible factors reducing the abundance of birds in treated areas, have been identified: 1) direct exposure through behaviours that bring birds into close contact with the chemical (Pearce and Peakall 1977; Buckner and Sarazin 1975; Pearce et al. 1979); and 2) indirect effects through decreased food availability, or the contamination of food (Doane and Schaefer 1971; Hunter and Witham 1985).

These two factors are the subject of this thesis. In chapter 1, the possibility of direct exposure is examined. Measurements of chemical residue were taken in different canopy regions to determine where the maximum deposit of fenitrothion occurred, and

therefore, the potential exposure of the birds. I then examined the effects of exposure to spraying on: long-term population trends, the behaviours of individuals present during the application, and their reproductive success. Behaviours of three bird species were examined for possible changes in: a) movement within the canopy; or b) allotment of time to specific behaviours. Chapter 2 deals with indirect effects on the bird's food source. Branch samples were taken before and after treatment, in order to measure changes in the amount of food available to birds. Drop trays were used to measure the amount of food removed from the tree subsequent to the treatment. Specific questions addressed were: 1) What was the magnitude and duration of insect drop from treated trees? 2) Was this increased drop related to a significant reduction of available food? 3) Was there a greater effect on invertebrates inhabiting areas of higher deposit?

Existing methods for determining sublethal and long-term effects on forest songbirds are not adequate. By using a combination of methods (census-mapping, mist-netting to mark and recapture individuals, and time-budget analyses of their behaviours) over a five-year field study, this thesis addresses the need for a sensitive, nondestructive method for measuring sublethal and long-term consequences of insecticide usage. This technique can be applied to other chemical and biological insecticides. Although biological control agents are less likely to cause a direct effect on birds, indirect effects through

decreased food availability could result. These effects could be assessed with time-budget analyses and captures of fledged young by mist-netting.

SUBLETHAL EFFECTS OF FENITROTHION ON FOREST PASSERINES

INTRODUCTION

A. Old Methods

Insecticides aimed at spruce budworm control occur during the breeding season of forest songbirds, coinciding with peaks in avian abundance and reproduction. Conventional censusing techniques to monitor pesticide impacts involve monitoring the singing activity of territorial males before and after treatment, on both treated and untreated control plots. A relative decrease in singing activity on treated plots is assumed to indicate a detrimental impact.

Monitoring of singing activity may be a suitable method when chemicals are used at high dosages. Songbird censuses (supplemented by carcass searches) in the 1960's showed that fenitrothion and phosphamidon, applied at rates recommended then (280-560g/ha and 280-1260g/ha respectively), adversely affected birds (Fowle 1965, Finley 1965, McLeod 1968, Pearce 1968, Buckner 1974, Bart and Hunter 1978).

During the last 10 years, however, less toxic insecticides have been used, and through refined application technology, the application rates of insecticides used previously (eg. aminocarb,

fenitrothion), have been reduced. Together, these factors have lowered the environmental hazards to birds. Consequently, methods geared at detecting immediate lethal effects need to be replaced with methods that measure sublethal and more long-term effects. Song censuses are incapable of detecting such subtle or minor impacts (Peakall and Bart 1983).

Problems with monitoring singing activity include: 1) large sample variability due to weather and migration which may mask insecticide-induced effects; 2) an inability to distinguish between emigration, mortality and behavioural changes that influence conspicuousness; and 3) immigration of birds from untreated areas into the treated area. It is not therefore clear what changes in census results should follow spray-induced effects.

B. New Conditions

Organophosphate insecticides reduce brain cholinesterase (ChE) levels in songbirds (Zinkl et al. 1979; Busby et al. 1981; Fleming and Grue 1981). The Canadian Wildlife Service now routinely use the ChE assay developed by Hill and Fleming (1982) as a monitoring tool to measure exposure of songbirds to forestry insecticide sprays. In their interpretation of changes in ChE activity levels following aerial insecticide applications, they have adopted the standards set by Ludke et al. (1975), that 20% ChE depression indicates exposure, and by Zinkl et al. (1979)

that 50% ChE depression signifies a life-threatening situation.

There are, however, 3 problems with this method: 1) because singing birds are collected, there may be a bias towards healthier individuals in the samples; 2) collection may be of individuals that immigrated into the treated area after treatment; and 3) the method is destructive, requiring the sacrifice of 100 or more birds. Furthermore, the biological significance (effects on behaviour and reproductive success) of different levels of ChE depression are not well known.

C. Background on the Program Design

Fenitrothion has been used in Canada since the late 1960's, and has been applied to millions of hectares of forest. It continues to be the major chemical insecticide for forest insect pests in Canada. In 1986, 300,000 hectares of Canadian forest were sprayed with fenitrothion (P.D. Kingsbury, pers. comm.)¹.

The toxicity curves (mortality of birds verses dosage) for fenitrothion are steep (NRCC 1975). Thus, small increases in the effective application rate, due to multiple swathing for example, may cause a sharply increased impact. In addition, the time scale of response may vary considerably with small changes in dosage. Immediate effects on adult mortality are expected at application

1. Project leader, Environmental Impact, Forest Pest Management Institute, Sault Ste. Marie, Ontario.

rates greater than 275gAI/ha (NRCC 1975; Peakall and Bart 1983). Breeding failure through juvenile mortality is expected between 206 to 275gAI/ha. Other sublethal effects on behaviour (e.g. changes in foraging, singing, and movements), are detected at rates greater than 138gAI/ha. The dosage rate at which long-term effects occur is unknown.

A dosage of 280gAI/ha was chosen for the present study because: 1) it is the maximum dose for forestry applications in Canada, and 2) from the above information it appears to be "borderline" in terms of its "safety" (i.e. lack of effects) on forest songbirds. A water formulation was chosen because studies by the Canadian Wildlife Service on ChE depression have involved this formulation, and it is the major formulation in use.

Stratification of the spray cloud may have an important effect on exposure of songbirds to aerial sprays. Warblers and kinglets, because they inhabit tree crowns, are thought to be highly susceptible to forest spraying (Pearce 1968; Buckner and Ray 1973; Busby et al. 1987). Most of the descending spray cloud is intercepted by the crown canopy of a dense forest (NRCC 1975). Ground-living birds may be less affected (Moulding 1976; Peakall and Bart 1983). Despite these conjectures, no one has attempted to relate songbird responses to deposit concentrations in specific regions of trees following the application of a chemical insecticide. I have shown that exposure does vary with canopy region (Appendix II).

Organophosphate exposure in birds is associated with decreased food intake and subsequent loss of body weight (Grue 1982). Birds are thought to search outside of the treated area for food only when the area treated is small enough that the bordering unsprayed area is nearby (Hunter and Witham 1985). Effects on food seeking behaviour (Adams 1977) may affect parental care, thereby influencing breeding success. Direct effects of fenitrothion on invertebrates last 2 to 4 days when large numbers of non-target insects are killed (Varty 1974; Chapter 2), and residual effects may last up to 30 days after spraying (NRCC 1975). Since even seed-eating birds may eat large numbers of insects during the breeding season, changes in feeding behaviour of songbirds should be a good measure of sublethal exposure to an organophosphate.

D. Feeding Behaviour

Many birds depend on insects during the breeding season as they are an essential food source for the young. Most wood warblers (Parulidae) eat all major orders of arboreal arthropods (MacArthur 1958). However, certain food items are preferred due to their caloric value, and ease of handling or capture (MacArthur 1958; Royama 1970; Garton 1979). Under conditions of low food abundance, however, a greater range of food items may be taken, and search time per item should increase (Schoener 1971). Travel time per item between patches should also increase if patches are reduced in size or number. Birds can readily find and

consume only a small percent of the total food present due to the increased effort required to find scarce prey (Kendeigh 1947).

By depressing the abundance of insects with a pesticide (carbaryl) Hunter and Witham (1985) found that 77 percent fewer warblers foraged in the sprayed area, and that they foraged lower in the canopy, and in a greater variety of trees. Doane and Schaefer (1971) found that a 99 percent kill of gypsy moth larvae forced birds to forage outside of the sprayed plots. Increased deposits in the tree crown can cause a differential decrease in insect abundance (Moulding 1976) which is thought to lead to increased effects on canopy feeding bird species (Hunter and Witham 1985).

To feed in areas of lower deposit, birds might need to change their foraging behaviour. Niche partitioning may decrease competition both within and between species (MacArthur 1958; Morse 1976). Therefore, movement of birds into new foraging sites may increase competition. When competition becomes intense effort may be diverted from necessary reproductive activities, or adults may raise their young to independence, but these young may suffer increased mortality after they become independent (Kendeigh 1947).

E. Objectives

The objectives of my study were:

- 1) to assess the short-term sublethal effects of forest spraying on native songbirds through: a) changes in the horizontal and vertical stratification of 3 common species of birds in relation to concentration of the deposit; b) changes in their feeding behaviour; and c) increased time spent in behaviours associated with organophosphate poisoning such as preening and bill-wiping;
- 2) to assess long-term sublethal effects through a comparison of: a) annual return rates; and b) annual fledging success, over consecutive years in the treated and untreated control areas.

My overall goal was to develop a sensitive method that could be used routinely in monitoring studies.

METHODS

1. Site Description:

A 200 ha section of second growth boreal forest, located 13 km NE of Searchmont, Ontario, in the Icewater Creek watershed, La Verendrye Township, was authorized by the Ontario Ministry of Natural Resources for long-term research into the environmental impact of forest insecticide applications. In 1983, an 8 ha study plot, in the centre of the proposed spray block (49.2 ha), was selected for detailed observations of forest songbirds (Plot T). A control plot for the 1985 application (4 ha), was set up in 1984, a further 5 km NE of this area, to eliminate the

possibility of drift from the aerial treatment (Plot C). This plot was smaller because of manpower limitations. However, the 3 species of interest (chestnut-sided warbler, Dendroica pensylvanica (L.), magnolia warbler, D. magnolia (Wilson), and white-throated sparrow, Zonotrichia albicollis (Gmelin)) were common within the plot. A second treatment plot of approximately 3 ha was established in 1986 (Plot T2). A portion of the first treatment plot was used as a control for the 1986 ground application. Due to the reduced drift associated with a ground application, the treated and control areas could be within the same valley. Consequently, observation sites on Plot T2 and the control were closely matched in 1986 (Figure 1.1).

Habitat analyses were conducted in all 3 areas using the James and Shugart (1970) method (Appendix I, Tables 1,2 and 3). The original treatment plot was reanalysed in 1986 due to an apparent successional change (Appendix I, Table 4), which could have influenced bird population trends in the area. Shrub growth increased considerably over the 3 years on plot T (ground cover increased from 73 percent to 92 percent). A large portion of the stand in all 3 areas was cut 10 to 19 years ago. This was a partial cut, leaving sections of spruce and fir that are now 45 to 65 years old. Rough calculations (Appendix I, Table 5) of the volume of balsam fir and white spruce foliage in the 3 areas (plot T, plot T2, and plot C) were 554m^3 , 718m^3 , and 1483m^3 , respectively.

Figure 1.1. Location of treatment and control plots for the aerial and ground applications.

Budworm populations prior to this study had increased from the late 1960's to cause the third and most severe outbreak in Eastern Canada since 1909 (Kettela 1983). In the study region, budworm declined from about 1800 larvae/m² foliage in 1983, and 240/m² in 1984, to 0 in 1987 (M. Applejohn pers. comm.²; see also Table 1.4). None of the 3 areas were sprayed prior to this study.

The treatment plots had natural borders to the southeast (Goulais River) and southwest (change in topography) which could limit movement in and out of the spray block; a problem in a number of impact studies (Peakall and Bart 1983). The habitat was second growth boreal forest (mean canopy height of 9 m). Although this was not a typical budworm forest, it was more amenable to study than a mature forest. Furthermore, birds inhabiting open areas and the upper crown of second growth trees, can receive a similar exposure to that of canopy-dwelling birds in a typical budworm forest (Moulding 1976; Pearce et al. 1979).

The 3 areas were similar in tree species composition. Predominant species of the first treatment plot (plot T) were Thuja occidentalis, Abies balsamea, and Betula papyrifera. Those of the second treatment plot (plot T2) were Abies balsamea, Picea glauca, Betula papyrifera, and Populus tremuloides. Predominant species of the control plot (plot C) were Abies balsamea, Picea glauca, and Betula papyrifera. Sections of Plot T were poorly

2. Chief, Forest Insect and Disease Survey, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario.

drained. Only the drier portion, identical in habitat to Plot T2, was used as a control for the second application. Plot C was drier than the other plots, and the trees were generally more mature (1 percent over 18 m).

2. Application of the insecticide:

Significantly higher levels of pesticide are deposited on the upwind side of the tree and in areas not filtered by other foliage (Armstrong and Yule 1978; Barry 1984). This produces a vertical gradient or stratification of deposit where lower canopy levels receive less deposit (Spillman and Joyce 1978; Sundaram and Nott 1984). Horizontal stratification has also been reported where less deposit reaches the inside foliage (Armstrong and Yule 1978; Sundaram et al. 1985).

In order to relate changes in bird behaviour to concentrations of deposit, deposit samplers were situated in each of the 5 canopy regions used for behavioural studies. Details of the method are given in Appendix II.

A. Aerial application

At 0730 on 14 June, 1985, fenitrothion was applied with a Cessna 188 aircraft equipped with 4 Micronair[®] AU3000 atomizer units, at a blade angle of 35°, as an emulsion in water at a total volume of 1.5 litres/hectare. The tank mix consisted of 15

percent technical fenitrothion (Sumithion[®]), 1.5 percent solvent (Dowanol TPM), 1.5 percent emulsifier (Atlox[®] 3409F), 1 percent tracer dye (Rhodamine B) and 81 percent water. The spray was applied 15 m above the tree canopy at a flying speed of 160 km/h with a swath width of 45 m. The dosage was 280 g active ingredient (AI) of fenitrothion per hectare. Meteorological conditions at the time of spray were: temperature $15 \pm 1^{\circ}\text{C}$, relative humidity 80 percent, wind speed 2 ± 0.5 km/h and no cloud cover.

Results of chemical analyses on the fate and distribution of fenitrothion following the application (Appendix II), indicated a definite gradient in deposit concentrations within balsam fir, decreasing from top to bottom and from periphery to inner tree canopy, presumably due to filtration of spray droplets by the needles. The ratio of deposit concentration from top to lower canopy levels was 1.7:1.3:1 for balsam fir. Inside foliage received approximately the same deposit as lower outside foliage. This stratification of deposit was not observed for white birch (Table 1.1). More deposit was received in mid and lower canopy regions of white birch, probably due to the geometry of the tree.

Poor weather conditions in 1985 for 3 days following the application (rain) prevented adequate sampling of bird behaviour, and may have enhanced degradation of the chemical. Consequently, the application was repeated in 1986.

Table 1.1. Fenitrothion deposits on foliage at different locations of the tree crown following the aerial and ground application.

SAMPLER LOCATION	AERIAL ¹		GROUND ²	
	FIR ³	BIRCH ³	FIR ³	BIRCH ³
top	75±20	66±22	61±12	38±13
mid-outside	54±16	90±25	43±13	46±12
low-outside	43± 8	71±20	41±14	36± 8
mid-inside	41±13	72±17	32±10	36± 9
low-inside	30± 4	64±17	18± 6	33± 8
overall mean±SD	49±23	73±27	39±15	38±15

¹ for the 6 sample trees; samples from 2 trees were pooled to provide 3 composite samples for analysis.

² nine sample trees were analysed separately.

³ analysis of the amount of deposit per surface area of foliage, expressed as ng per cm.

B. Use of a ground application to simulate the 1985 aerial application

In April of 1986, the Ontario Minister of Natural Resources decided not to allow any aerial applications of chemical insecticides to Ontario crown forests. This ban included applications for either research or pest control.

It was therefore necessary to resort to a ground application. For a valid comparison between application years, both the dosage and stratification of the deposit had to be replicated. In the area selected (Plot T2), 64 percent of the trees were less than 15 cm in diameter, and 86 percent were less than 23 cm in diameter (a height of less than 12 meters). Therefore, a ground application could provide the coverage needed for trees of this size.

There are two possible ways of conducting a ground application to simulate an aerial spray. Hopewell (1974) developed a technique for applying a simulated aircraft spray to individual trees using a spinning disc nozzle. A static or directed application such as this does not, however, allow for stratification of the deposit.

On the other hand, spraying in swaths through the forest allows the deposit to be carried into the trees as it would be from an aerial application. Stratification occurs because of

differing wind speeds within the different canopy heights (N. Payne pers. comm.)³. As with aerial applications, some wind movement was necessary for a predictable movement of the spray cloud.

The spraying of individual trees in a directed fashion, was also rejected due to the problem of immigration of insects from the surrounding vegetation onto the sprayed tree, giving different recolonization results from that of an aerially treated block.

I therefore used a Solo port 423 backpack mistblower (70 ml engine capacity) with the nozzle pointing straight up in the air, in order to take the spray above the canopy. The mistblower was fitted with a 2 meter extension tube and a booster pump which increased the vertical throw of the spray to about 15 meters. In this way, the spray cloud diffused back down over the canopy, imitating an aerial application. The extension tube was fitted with a diffuser nozzle to control droplet size.

Parallel trails were cut 20 meters apart throughout the area. These swath lines were oriented perpendicular to the prevailing wind direction to allow the wind to dissipate the spray cloud and thereby even out the deposit. All overhead branches were removed and the path was cut wide enough to permit

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unobstructed walking so that a constant walking speed could be maintained.

The equipment was calibrated, using a formulation to mimic the specific gravity and viscosity of fenitrothion (triethyl phosphate 4.3 percent, Atlox 3409F 1.5 percent, Dowanol TPM 1.5 percent, Rhodamine B 1.5 percent and water 91.7 percent), to determine the actual flow rate of the mistblower with the extension tube. The formulation was then adjusted for the mistblower application rate to maintain a dosage of 280 g AI/ha. The tank mix consisted of 4.5 percent fenitrothion (.224 liters), 1.5 percent Atlox 3409F (.075 liters), 1.5 percent Dowanol TPM (.075 liters), 1.0 percent Rhodamine B dye (.05 liters), and 91.5 percent water (4.576 liters).

With both the formulation (the amount of AI/ha of tank mix), and the volume emission rate (dependent on the mistblower flow rate) fixed, only the walking speed could be adjusted. Therefore, having calibrated the flow rate to be 312 ml/min, and knowing both the swath width (20 meters) and the area to be covered (2.434ha), the required walking speed would be 0.52 m/sec.

C. The Ground application

Fenitrothion was applied between 1107 and 1156 on 18 June, 1986. One person set the walking pace using 20 m flagged stations. The applicator followed behind holding the nozzle

vertically upwards, emitting the spray at the maximum flow rate (312 ml/min). A third person recorded the time elapsed for each line. Meteorological conditions during the spray application were: wind speed 9.6 ± 1.0 km/h, temperature $21 \pm 1^\circ\text{C}$, RH 50 percent, and no cloud cover.

From the total volume emitted (12.667 liters) and the area treated (2.434 ha), the actual application rate was 5.2 liters/ha or 292.5 g AI per hectare (about 4% higher than estimated).

Stratification of the deposit was similar to that of the aerial application where the maximum deposit was received in tree crowns and in the peripheral foliage of balsam fir (Table 1.1). The smaller droplets produced by the mistblower application were poorly collected by white birch foliage. This was probably due to the low humidity during the application (A. Sundaram pers. comm.)⁴. Very little deposit reached the ground (1.7 g/ha) compared to the aerial application (73 g/ha), suggesting a more effective collection of the mistblower spray by the foliage.

3. Bird populations of Icewater Creek:

The bird communities of Icewater Creek were characterized during the summers of 1983 and 1984. Stages of the breeding cycle were determined using the breeding condition of individuals

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caught in mist nets, changes in singing activity over the season, and observations of breeding behaviour (activity at the nest, for example).

The breeding season extends from mid-May to the end of July, when the young have fledged, and territories have broken up. Diversity of birds in the area was high (34 species of territorial birds). Populations of the 3 indicator species averaged 1.8 per ha for chestnut-sided warblers, 2.5 per ha for magnolia warblers, and 2.8 per ha for white-throated sparrows. Forty percent of all territorial birds counted belonged to the 3 indicator species.

4. Effects of fenitrothion on forest songbirds:

A. Long-term Effects:

Censuses were conducted using a plot method (Kendeigh 1947) to record all singing and sighted birds. A 40 m grid was flagged for plotting bird locations. The location of each individual observed was mapped for delineating territories. Two observers sampled each area in opposite directions to remove the effects of observer bias, and to control for effects of time of day on activity. One 8 ha plot (plot T) was censused from 1983 to 1987. A second 4 ha plot (plot C) was censused from 1984 to 1987, and a third 3 ha plot (plot T2) was censused only in 1986 and 1987. Censuses for the third plot in 1986 were taken from time-budget

observation sites.

Changes in relative abundance were also estimated by mist netting. Nets were sampled simultaneously in treated and untreated control areas. They were dispersed throughout the study areas. The return of individuals to each area was determined from recaptures of individuals in mist nets the following year.

B. Medium-term Effects:

All indicator species were common to the area, easy to observe, and potentially sensitive to aerial applications. Some individuals of these species were colour-banded to facilitate identification. Different colours were used to identify males and females.

White-throated sparrows occupy open habitats where they may receive a similar spray exposure to crown-inhabiting species that are more difficult to study (Busby et al. 1983). The magnolia warbler is also an edge species inhabiting mainly balsam fir at the mid-canopy level. Chestnut-sided warblers also forage in mid-canopy, but mainly in deciduous tree species.

Preliminary observations of all 3 species revealed intraspecific differences in behaviour. Females were more active later in the morning, tended to be lower in the tree and further inside the canopy (see also Morse (1968)), and they apportioned

their time differently from males of their species. Females were not included in detailed analyses as they could not be observed in large enough numbers. Preliminary studies also showed that the main activity period was a 4 hour period beginning a half hour after sunrise.

Behavioural observations were taken at evenly-distributed sites throughout treated and untreated control areas over the study period (9 June to 3 July in 1986, and 28 May to 26 July in 1985). Sites were chosen where visibility of birds was good, and where all canopy regions were visible. These sites were sampled in random order, and were randomly assigned among observers. Observations were conducted simultaneously in the treated and untreated control areas. Observations at each site lasted for 20 minutes. During this time, each bird seen was recorded for as long as it was present, and the start and finish times of each behaviour and move the bird made were noted on a data sheet. The location and behavioural categories used are listed in Table 1.2.

To eliminate the effect of tree height on foraging height, I expressed foraging height as a proportion of tree height. Foraging heights were thus converted to the canopy region utilized (top, mid, or low).

All observations were related to chemical residue measurements, taken in the same canopy regions. Stratification of the deposit was expected to influence bird behaviour through

Table 1.2. Location and behavioural categories used in the time-budget observations.

LOCATIONS:

BEHAVIOURS:

Social	{	Singing and territorial defense Courting Call (Alarm or other) Nest building
Maintenance	{	Sitting and looking Preening Bill wiping
Feeding	{	Flycatching Hawking Hover-gleaning Gleaning Peck and Hammer Probe Carrying food Searching

avoidance of the chemical and/or depletion of food available through a chemical-induced kill of invertebrates.

Reproductive success was estimated by: a) the number of fledglings caught in mist nets in treated and untreated areas; b) observations of nests found within both areas; and c) observations of adult birds feeding their young. The capture date of fledglings was also compared for treated and control areas.

C. Immediate Effects:

Immediate effects were determined by changes in singing activity, and by movement of individuals out of the treated area.

RESULTS

Effects of fenitrothion on forest songbirds:

A. Long-term population trends:

1) Census results and territory analysis:

Abundance of territorial birds increased on the control plot (Plot C) before spraying, but declined slightly on the treated plot (Plot T) (Figure 1.2). Abundance on both the control and treated plots declined at about the same rate in the year following treatment.

Figure 1.2. Population trends of territorial birds (all species) on treated (Plot T) and control (Plot C) plots, from 1983 to 1987. The number of birds ($\bar{x} \pm SD$) are expressed per hectare. Fenitrothion was applied in 1985 on Plot T.

Numbers of warblers were significantly lower ($p < .005$, regression, slope = -3.6, $df = 5$) in 1986 than 1985 on the treated plot, but not on control ($p > .05$). Populations of all other groups of birds on the treated plot fluctuated as expected from the control trends (Figure 1.3).

Populations of the three indicator species were not significantly reduced within the year of treatment ($p > .05$, ANOVA, $df = 1, 15$). Although the number of territories of these 3 species declined over the study period, a similar proportion of the original territories were still occupied in 1987 on treatment and control plots. The most notable decline was for the chestnut-sided warbler between 1986 and 1987 (Table 1.3).

Table 1.3. Long-term changes in the number of territories of the chestnut-sided warbler, magnolia warbler, and white-throated sparrow.

	1983	1984	1985	1986	1987
<hr/>					
PLOT T					
Species:					
chestnut-sided	13	13	9	8	3
magnolia	12	12	12	11	9
white-throat	13	8.5	7	7	6
<hr/>					
PLOT C					
Species:					
chestnut-sided	-	11	12	10	4
magnolia	-	8	10	9	6
white-throat	-	9.5	6	6	4
<hr/>					

2) Change in budworm-feeding species:

Figure 1.3. Population trends of the major bird groups (A= warblers, B= thrushes, C= flycatchers, D= kinglets, E= vireos, F= white-throated sparrows) on treatment (Plot T) and control (Plot C), from 1983 to 1987. The number of birds ($\bar{x} \pm SD$) is expressed per hectare. Fenitrothion was applied in 1985 on Plot T.

One explanation for the general decreasing trend in bird abundance on both plots (Figure 1.2), is that cyclic declines in abundance of spruce budworm may cause budworm-feeding bird species to decrease in numbers (Morris et al. 1958). Since budworm populations in Northeastern Ontario have been decreasing from 1981 (Table 1.4), one might expect budworm-associated bird species to have decreased in abundance over the study period (1983 to 1987). Control results are consistent with this hypothesis, as there has been a significant reduction in numbers of budworm-feeding species (the tennessee, Vermivora peregrina (Wilson), blackburnian, D. fusca (Müller), bay-breasted, D. castanea (Wilson), and cape-may, D. tigrina (Gmelin), warblers, and the evening grosbeak, Hesperiphona vespertina (Cooper); $p < .005$, regression, $df=23$, slope = $-.7$). Numbers of these species were initially low on plot T, and did not change over the study period. Habitat differences on the 2 plots may have contributed to the differing responses to budworm. The habitat for budworm and the associated bird species was more suitable on plot C (1% trees of greater than 12m), and in the forest adjacent to this plot.

An inverse numerical response is expected for the magnolia, yellow-rumped, D. coronata (L.), and black-throated green, D. virens (Gmelin) warblers because they are outcompeted by budworm specialists (Morris et al. 1958). There was a slight overall (1984 to 1987) increase (.53 birds per hectare) of these species on plot C. The increase from 1984 to 1986 ($p < .01$, regression, $df=19$, slope = 1.22) was 2.48 birds per hectare; corresponding to a

Table 1.4. Gross area (ha) of moderate-to-severe defoliation (current) by spruce budworm from 1983 to 1986¹.

Region	District	Area of moderate-to-severe defoliation			
		1983	1984	1985	1986
Northeastern	Sault Ste. Marie	669,875	30,255	7,875	--
	All districts	4,533,718	2,203,389	1,522,757	14,504
North Central	All districts	2,039,030	3,879,876	6,211,392	--
North Western	All districts	774,634	1,667,801	3,403,547	--
Total		9,039,862	8,747,852	12,332,365	8,855,687

¹ adapted from Thomson et al. 1985

decrease of 2.15 birds per hectare of budworm-related species over the same period. This increase was not observed on plot T, and was not expected since there was no change in numbers of budworm-related species (Figure 1.4). Control results suggest that a response to budworm populations occurred in the Icewater Creek area where there was appropriate habitat. Fluctuations in budworm numbers do not seem to have influenced bird population trends on plot T, however.

Abundance of other bird species, not influenced by budworm populations, followed the same trend on control and treatment plots (Figure 1.5). This suggests that other factors (environmental conditions on the wintering grounds or during migration, for example) had a greater influence on population trends than the treatment.

3) Relative abundance of species as determined by mist netting:

Contrary to the trends exhibited in the census results, the number of birds caught per net hour on treatment (plot T) was not lower in 1986 than 1985 (Table 1.5). The proportion of males caught in 1986 was lower than in any other year on either plot, however (38 percent on plot T in 1986 versus an average in other years of 44 percent on plot T and 42 percent on plot C; Table 1.5). As the males have a greater potential for exposure to insecticide sprays than females, this suggests a reduced return of males related to the treatment.

Figure 1.4. Change in abundance of budworm-associated bird species (A), and bird species known to have a negative numerical response to budworm numbers (B), from 1983 to 1987, on treated (Plot T) and control (Plot C) plots. Numbers of birds ($\bar{x} \pm SE$) are expressed per hectare.

Figure 1.5. Population trends of bird species not influenced by budworm populations, from 1983 to 1987, on treated (Plot T) and control (Plot C) plots. Numbers of birds ($\bar{x} \pm SE$) are expressed per hectare.

Table 1.5. Change in population structure on plot T, from 1983 to 1987, and on plot C, from 1984 to 1986, as determined by mist-netting. Numbers represent original captures for the respective year, expressed per 100 net hours. The categories for each group are: the total number of birds caught (T), number of males (M), number of females (F), and the number of juveniles (J).

Plot T	1983				1984				1985				1986				1987		
	T	M	F	J	T	M	F	J	T	M	F	J	T	M	F	J	T	M	F
Flycatchers	2.8	0.7	1.9	0.2	3.1	1.0	1.5	0.6	2.4	0	1.9	0.2	2.5	.3	1.8	.3	2.4	.9	1.3
Thrushes	6.0	3.0	1.8	1.3	5.1	2.3	1.2	1.2	3.5	1.6	1.4	0.3	4.5	1.3	1.7	1.0	3.3	1.9	1.4
Red-eyed vireo	0.7	0.1	0.4	0	1.6	0.8	0.6	0.2	1.0	0.2	0.5	0.1	0.9	0.5	0.2	0	0.9	0	0.9
Warblers	18.1	9.7	5.9	2.0	24.9	9.8	8.4	5.6	26.3	11.1	9.2	4.3	27.4	11.0	8.6	7.6	17.9	10.3	8.0
Purple finch	0.5	0.3	0.1	0.1	1.0	0.2	0.2	0.4	0.3	0	0.2	0	0.3	0.1	0.1	0	0	0	0
White-throated sparrow	4.8	1.5	1.2	1.8	3.2	1.3	0.4	1.2	2.1	1.3	0.5	0.3	2.7	1.1	1.1	0.5	3.8	2.4	1.4
All territorial birds	33.7	15.4	11.6	5.8	39.6	15.7	12.5	9.4	36.3	14.3	13.9	5.4	39.2	14.4	14.0	9.5	28.2	15.5	13.1
Proportion of catch ¹		46.9	35.3	17.3		41.8	33.1	23.9		42.4	41.4	15.0		37.9	36.7	24.6		-	-

Plot C	1984				1985				1986		
	T	M	F	J	T	M	F	J	T	M	F
Flycatchers	0.1	0.1	0	0	0.4	0.1	0.3	0	1.4	1.1	0.4
Thrushes	3.8	1.0	1.1	1.1	4.5	1.4	2.0	0.7	1.4	1.1	0.4
Red-eyed vireo	0.7	0.1	0.1	0.1	0	0	0	0	0	0	0
Warblers	22.2	8.4	6.8	4.8	22.0	9.6	8.6	3.3	17.5	11.2	6.3
Purple finch	0.1	0.1	0	0	0	0	0	0	0	0	0
White-throated sparrow	4.1	1.8	1.1	1.1	3.9	1.5	1.4	1.1	2.8	2.1	0.7
All territorial birds	31.0	11.9	9.12	7.1	30.8	12.6	12.2	5.0	23.1	15.4	0.1
Proportion of catch ¹		42.3	32.5	25.2		42.3	40.9	16.8		-	-

¹ Only adults that could be sexed were included in this calculation.

The lowest proportion of young caught (15 percent) occurred on plot T in 1985 (Table 1.5). This agrees with a hypothesis of reduced fledging success in the year of the application. However, a low proportion of young was also obtained on the control plot in 1985 (16.8 percent), suggesting that this was a poor year for breeding. The number of fledgling white-throated sparrows caught on plot T during 1985 and 1986 was lower than 1983 or 1984 and lower than control. The number of male white-throated sparrows returning in 1986 was also lower than other years and lower than control. The number of fledgling magnolia and chestnut-sided warblers was not, however, lower in the year of treatment nor were the numbers of warblers as a whole.

A better index of the effects of spraying is the return rate of marked birds. If the application had a significant effect, the number of recaptures on the treatment plot in the year after spraying should have been unusually low. Individuals of territorial species caught the year of the application (1985), on plot T, returned the next year at a lower rate (7.4 percent) than those first caught in 1983 or 1984 (16.3 percent and 19.3 percent, respectively). The return rate for 1985 captures on treatment was also lower than that of control for any year (range of 14.2 to 21.8 percent).

B. Medium-term response:

1) Movement of birds:

To examine the possibility that birds avoided the spray, time-budget observations of the 3 indicator species were analyzed separately to test for changes in occurrence of birds after the application. Data were gathered simultaneously in the control area. These data were analyzed for the 5 canopy regions (top, mid-outside, low-outside, mid-inside, low-inside). Only males are considered in the analysis, because they were more observable than females.

Data were presented as the number of times a banded individual was observed, divided by the total number of observations taken. The total number of observations was calculated as the number of sites visited per day, multiplied by the number of days of observation. These proportions were compared before spraying, immediately after spraying, and more than 5 days after spraying, for both treated and control areas.

There was no indication from the proportion of individuals observed, that chestnut-sided warblers left the treated plot after either application (Figure 1.6 A). In fact, in 1986 individuals were observed more often after the treatment. Control results in 1986 did not show this increase in activity, except for increased observations in the top canopy region (Figure 1.6 B). Treatment results from 1985 exactly follow trends on the control (i.e. chestnut-sided warblers became less visible over the study period on both plots). More individuals were observed in areas of lower concentration of deposit after treatment,

Figure 1.6. Comparison of changes in the proportion of observations taken ($\bar{x} \pm SE$) in which individual chestnut-sided warblers were observed, on the treated and control plots, from before treatment (T_1) to after treatment (T_3), for both application years. A= all canopy regions. B= individual canopy regions.

relative to control. But areas of higher concentration of deposit did not have fewer individuals, relative to changes on control. This suggests that chestnut-sided warblers did not move to avoid the deposit.

Unlike the chestnut-sided warblers, magnolia warblers were generally less visible immediately following both applications (Figure 1.7 A). Control and treatment trends for each canopy region (Figure 1.7 B) were quite similar for both years, the exception being that more individuals were observed mid-inside after the application on the treated plots. This is consistent with a preference for less exposed (in terms of deposit) regions of the tree, but the increase was not significantly different from the change on control ($p > .05$, z-test). There is no indication that magnolia warblers left the treated area in either application year.

White-throated sparrows were also observed more frequently in less exposed canopy regions (i.e. low-outside and mid-inside) on the treated plots after application than in control plots (Figure 1.8 B). This movement was significantly different from that of control in both years for low-outside, but only in 1986 for mid-inside ($p < .05$, z-test for change in proportion). Additionally, fewer individuals were observed in more exposed canopy regions (i.e. mid-outside for both application years, and top for 1986 only). This suggests movement away from areas of higher deposit. The trend was consistent for mid-outside and top

Figure 1.7. Comparison of changes in the proportion of observations taken ($\bar{x} \pm SE$) in which individual magnolia warblers were observed, on the treated and control plots, from before treatment (T_1) to after treatment (T_3), for both application years. A= all canopy regions. B= individual canopy regions.

Figure 1.8. Comparison of changes in the proportion of observations taken ($\bar{x} \pm SE$) in which individual white-throated sparrows were observed, on the treated and control plots, from before treatment (T₁) to after treatment (T₃), for both application years. A= all canopy regions. B= individual canopy regions.

canopy regions, but not significantly different from control ($p > .05$, z-test).

2) Behavioural changes within the spray block

To assess whether individuals remaining in the block changed their behaviour after spraying, analysis was directed at how individuals present allocated their time. Observations were therefore expressed as a proportion of the bird's time spent in various behaviours. For simplicity, behaviours were grouped as social, maintenance, and feeding behaviours. Only males were considered in the analysis.

Individuals of the 3 indicator species did not allocate their time differently among the 3 behavioural categories after either application on the treated plot as compared to observations taken before the application, or observations taken simultaneously on control (for example, Figure 1.9). There was an increase in the average proportion of time spent feeding after the 1986 application for both chestnut-sided warblers and white-throated sparrows, but this increase was not significant ($p > .05$, Kruskal-Wallis test). Similarly, Magnolia warblers spent an increased proportion of their time in maintenance behaviours after the 1986 application, beyond that expected from control (Figure 1.10), but again this difference was not significant ($p > .05$, Kruskal-Wallis test).

Figure 1.9. Comparison of the proportion of time magnolia warblers spent in social, maintenance, and feeding behaviours, over the 1985 study period, on treated and control plots. Time periods T₁, T₂, and T₃, represent the observations: prespray, immediate postspray, and later postspray, respectively.

Figure 1.10. Comparison of the proportion of time magnolia warblers spent in maintenance behaviour before treatment, immediately after treatment, and later after treatment, on treated (Plot T), and control (Plot C) plots, in 1986.

Changes in feeding behaviour were analyzed in more detail. Warblers spent less time foraging immediately following treatment (a decrease of 42 % in the proportion of available observation time spent foraging; versus an increase of 266 % on control in 1986; a decrease of 61 % on treatment and a decrease of 6 % on control in 1985), in both deciduous and coniferous trees.

The proportion of warblers feeding in coniferous trees on the treated plot did not differ from that on the control plot in 1985, and did not change after treatment in 1986. Of the three indicator species, the magnolia warbler was the only species to decrease its use of coniferous trees after both applications (a decrease of 54 % in 1985 and 64 % in 1986). The corresponding results for control were an increase of 100 % in 1985 and a decrease of 5 % in 1986. This decreased use was also apparent for deciduous trees, however, and consequently, the decreased use of conifers may merely reflect decreased foraging activity of magnolia warblers in general. White-throated sparrows showed no change in tree species use following the 1986 application, but a slight decrease (25 %) in the proportion of foraging observations in conifers following the 1985 application (control observations increased but the sample size was small). Chestnut-sided warblers did not utilize conifers in the treated areas.

Magnolia warblers foraged mainly in mid-canopy, but also in the tops of both coniferous and deciduous trees. Individuals foraging immediately after spraying in both application years

moved from the outside to inside foliage of the deciduous trees (no individuals were observed top or mid-outside after either application on treatment, whereas, 4/5 and 5/5 individuals utilized these canopy regions before the 1985 and 1986 applications respectively; no individuals were observed feeding in deciduous trees on control in 1985, but 7/16 individuals continued to feed in top or mid-outside regions immediately after the 1986 application on control). Individuals continued to forage in the top and mid-outside of coniferous trees after both applications on both plots. There were no observations of attack maneuvers in either tree species on the treated plot immediately after the 1986 application, yet 9/14 individuals on control were observed in these behaviours. After the 1985 application, the total proportion of time magnolia warblers spent in attack maneuvers decreased by 71 % on treatment; on control, the total proportion of time decreased by 13 %.

White-throated sparrows fed over the entire tree, but mainly in the mid-canopy of both coniferous and deciduous trees. The location of foraging maneuvers was not noticeably different after the treatment. More individuals were observed feeding immediately after the 1986 application; no increase was observed on the control in 1986, or on either plot in 1985 (Table 1.6). The increased frequency of feeding observations was mainly a difference in the frequency and proportion of time spent carrying food (Table 1.7). It is possible that food was carried from outside the sprayed area, as individuals were observed flying

Table 1.6. Numbers of white-throated sparrows observed feeding in treated and control plots before, immediately after, and later after the 1985 and 1986 application. The number in brackets is the frequency expressed as a proportion of the number of observation samples taken during that time period.

APPLICATION	NUMBER OF INDIVIDUALS OBSERVED FEEDING		
	PRESPRAY (T1)	IMMEDIATE POSTSPRAY(T2)	LATER POSTSPRAY(T3)
1986-treatment	5 (.045)	12 (.125)	15 (.165)
-control	10 (.089)	10 (.102)	7 (.082)
1985-treatment	6 (.061)	6 (.050)	9 (.076)
-control	2 (.035)	2 (.032)	1 (.015)

Table 1.7. Number of white-throated sparrows observed carrying food. The number in brackets is the proportion of time spent carrying food, out of the available time, expressed as a percent.

APPLICATION			
	PRESPRAY (T1)	IMMEDIATE POSTSPRAY(T2)	LATER POSTSPRAY(T3)
1986-treatment	1 (.008)	6 (.365)	3 (.06)
-control	1 (.007)	0 (0)	0 (0)
1985-treatment	0 (0)	1 (.011)	3 (.047)
-control	0 (0)	0 (0)	0 (0)

across the spray block boundary. However, birds may also have foraged outside the control plot.

Chestnut-sided warblers fed throughout deciduous trees; most commonly in white birch. They prefer the mid-canopy where insecticide deposits concentrate. Following the 1985 application, individuals no longer fed in the tops of deciduous trees but still fed in the mid-outside. In 1986 also there was no significant difference in the proportion of time spent feeding in areas of potentially high residue (top and mid-outside of conifers; top, mid-outside, and low-outside of deciduous) on treatment or control, for any time period. There were fewer observations of feeding behaviour in the 1985 treated plot. However, those individuals observed immediately after the 1985 application did increase the proportion of time they spent searching (Figure 1.11). In 1986, individuals spent more time foraging immediately after spraying; this may have been related to increased demands of the young. The proportion of time spent in search maneuvers increased 2.3 fold on control, and 2.5 fold on treatment.

The proportion of birds observed carrying food on the treated plot that were not first observed feeding in the plot, was higher immediately following the 1986 application than for any other time period on either plot (Table 1.8). There were too few observations of carrying behaviour on the control plot in 1985 to compare between years.

Figure 1.11. Comparison of the proportion of time chestnut-sided warblers spent searching for food before treatment, immediately after treatment, and later after treatment, on treated (Plot T) and control (Plot C) plots, in 1985.

Table 1.8. Proportion of birds that were observed carrying food without previously feeding in the spray block. The data are expressed as a proportion of the observations taken. The number of observations of carrying behaviour are given in brackets.

	PRESpray	IMMEDIATE POSTSPRAY	LATER POSTSPRAY
1986:			
TREATMENT	.40(5)	.60(15)	.38(13)
CONTROL	.33(3)	.43(7)	.40(5)

Table 1.9. Comparison of the mean ($\pm$ SE) fledgling weights of the three indicator species on treated and control plots. Fenitrothion was applied in 1985 and again in another location in 1986; 1983 and 1984 were prespray years.

	1983	1984	1985	1986
CHESTNUT-SIDED WARBLER				
Treatment	10.2	9.5 $\pm$ 0.3	9.4 $\pm$ 0.3	9.8 $\pm$ 0.2
Control	-	10.4 $\pm$ 0.4	9.5 $\pm$ 0	9.8 $\pm$ 0.2
MAGNOLIA WARBLER				
Treatment	8.2 $\pm$ 0.4	9.1 $\pm$ 0.4	8.6 $\pm$ 0.4	8.4 $\pm$ 0.2
Control	-	9.3 $\pm$ 0.6	8.6 $\pm$ 0.3	8.3 $\pm$ 0.1
WHITE-THROATED SPARROW				
Treatment	23.9 $\pm$.5	19.7 $\pm$ 2.1	23.9 $\pm$ 1.3	21.9 $\pm$ 0.4
Control	-	22.9 $\pm$ 1.3	23.9 $\pm$ 0.4	23.1 $\pm$ 0.5

3) Numbers and weights of fledglings on control and treatment plots

There was no apparent reduction in weights of young magnolia warblers, chestnut-sided warblers, or white-throated sparrows, fledged from the treated plot, in either application year (Table 1.9). These young were caught in mist nets. A comparison of the number of young fledged was given with the long-term effects.

If nesting attempts had failed, I expected individuals to remain in breeding condition longer than those individuals that successfully fledged their first brood. Breeding condition was measured by brood patch development, and cloacal protuberance. A comparison of the breeding condition of birds mist netted in treatment and control in 1985, shows that individuals of territorial species came out of breeding condition slightly earlier on control, which may indicate that more individuals renested on treatment (5 of 13 females caught on control during the period from 18 to 20 July had finished breeding as judged from refeathering of the brood patch, while only 5 of 43 females were finished on treatment; 8 of 14 males caught on control during the same time were not breeding as compared to 7 of 23 males on treatment).

C. Immediate response

I observed no immediate mortality, reduction in singing

activity, or movement of individuals out of the treated area. Birds banded before the application were observed again in the area afterwards. The proportion of new birds caught in mist nets after treatment was lower in the treated area than the control in both application years (Table 1.10). This suggests that there was no emigration from the spray block; if territories within the sprayed area were abandoned, they might have been reoccupied by non-territorial males from elsewhere.

Table 1.10. Comparison of the proportion of adult individuals caught in mist nets after spraying in 1985 and 1986, on treated and control plots.

NETTING PERIOD	TREATMENT	CONTROL
1985		
18-21 June	.33	.55
3-5 July	.51	.61
17-19 July	.61	.76
1986		
8-9 July	.63	.72
16-18 July	.49	.73

Two male common yellowthroats, caught in mist nets 4 days after the 1985 application on the treated plot, exhibited involuntary muscle control followed by terminal wing-beat convulsions (signs of intoxication by fenitrothion (Hudson et al. 1984)). Their ChE levels were 12.46 and 14.45 $\mu\text{moles/min/g}$ brain tissue. The normal range of uninhibited ChE values is 25 to 30 $\mu\text{moles/min/g}$ brain tissue (D. Busby pers. comm.)⁵. Inhibition of

5. Biologist, Canadian Wildlife Service, Fredricton, New Brunswick.

over 50 percent indicates death from pesticide poisoning (Ludke et al. 1975). Assuming the lowest uninhibited level, these common yellowthroats were 42 and 50 percent inhibited. In this instance, pesticide poisoning and the stress of netting may have combined to cause death.

SUMMARY OF RESULTS

1) Long-term population trends of territorial birds were not affected by treatment; 2) although warblers on treatment and control showed different population trends, this was mainly because birds on control responded to changing budworm populations, whereas, birds on the treated plot did not; 3) a lower proportion of young were caught in mist nets on the treated plot in 1985 than expected from control numbers or from other years on the treated plot; 4) a lower proportion of the catch on the treated plot were males in 1986; 5) birds returned at a lower rate the year following treatment on the treated plot; 6) none of the indicator species abandoned the treated area after either application, although, there was some indication that white-throated sparrows and magnolia warblers moved away from foliage regions with higher deposits; 7) there was no significant change in allotment of time to social, maintenance, or feeding behaviours, for any of the indicator species; 8) chestnut-sided warblers and white-throated sparrows continued to forage actively on sprayed plots or nearby; 9) magnolia warblers decreased their foraging effort on the treated plot after both applications.

DISCUSSION

A. A new approach for assessing impacts of insecticide spraying on forest birds

The main objective of this study was to develop a method for measuring sublethal and long-term consequences of insecticide usage. The method outlined here is a workable monitoring tool, but requires considerable expertise. Mist netting is valuable for estimating: 1) the number of fledglings in treated versus control areas; 2) the approximate date of cessation of breeding (e.g. due to interruption by spraying); 3) movement of birds into and out of the sprayed area; and 4) long-term population trends. Behavioural observations are of value in assessing short-term impacts such as: 1) response to changes in food availability; and 2) movements related to insecticide deposit (exposure).

For behavioural changes to be detected, observations must be taken within 5 days after the application. In ducks, signs of fenitrothion intoxication can appear as soon as 30 minutes after treatment; deaths usually occur between 1 hour and 4.5 days (Hudson et al. 1984). Small songbirds also respond rapidly when orally dosed with fenitrothion; the effects usually last less than 24 hours if the bird survives (S. Holmes pers. comm.)⁶. In the field, however, additional exposure may occur after the

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actual spray (e.g. through eating contaminated food). Secondary effects of decreased availability of food could also be manifested over a longer period. For these reasons, behaviour samples geared at detecting initial exposure should be concentrated over the first 2 days following the application, but samples designed to measure the effect of a decreased food source or continued exposure, should be extended to at least 5 days after spraying.

The certainty of some conclusions of this study are limited by four problems:

- 1) Small sample size. Although the area was productive for birds, the number of residents per plot that could be sampled was still small;
- 2) Short time windows. Sampling effort was concentrated over a 2 month period. Any effects of treatment may be dampened by the longer time-scale effects of migration pressures and the situation on the wintering grounds;
- 3) Poor weather conditions immediately following the 1985 application. A sufficient number of behaviour samples could not be collected immediately after the treatment. As 50 percent of residues on foliage will be lost within the first 4 to 8 days (NRCC 1975), behavioural responses during the initial postspray samples in 1985 may have been similar to those seen in the later postspray time period of the 1986 application;

- 4) The small area treated in 1986 may have allowed individuals to forage outside the spray block, or to immigrate rapidly from outside the plot. There was, however, no evidence of immigration from observations of marked birds.

Some of these problems could be overcome through slight modifications of the method. It would be possible to increase the number of observations per session by following individuals. However, preliminary work with this method showed that: 1) it caused considerable interference by the observer; and 2) it selected for conspicuous individuals and conspicuous behaviours, and therefore, did not provide an equal chance of observing individuals in less exposed regions of the tree. I therefore chose to use, and recommend, focal-animal sampling with a stationary observer. In this way, the stopping rule is both independent of behaviour and independent of the observer's motivation.

Sample sizes could be increased by selecting individual territories for observation, rather than sampling areas that may contain few individuals of each species. Behavioural observations could also be improved by concentrating the time-budgeting effort on feeding behaviour. Most effects should occur within 5 days of treatment. This requires intensive efforts directed over a short time, but would work well in a province such as New Brunswick where plots in the north could be as much as 2 weeks behind the south in phenology. This could then be supplemented with mist

netting, before and after behavioural observations, for the marking of individuals, to determine fledging success, and to determine the return of individuals the following year.

B. Immediate and medium-term effects

Birds did not abandon territories within the sprayed area following either application. Individuals banded before the applications, were observed again afterwards. In 1985, individuals remained, but there was evidence that their fledging success decreased. In 1986 however, fledging success was not affected, possibly because individuals were able to forage in unsprayed areas. At least some individuals carried food in from outside the spray block. I did not however, measure movement across plot boundaries systematically.

I expected that birds foraging within the treated plot would have been forced to change their behaviour to obtain sufficient food. None of the indicator species partitioned their time differently between social, maintenance, and feeding behaviours after treatment. Foraging efforts were, however, redirected by:

1) more movement to locate prey Differences in abundance, distribution, and the kind of prey available in each canopy region influence patterns of bird locomotion (Paszkowski 1982). An insecticide-induced change in abundance should alter patterns of locomotion. Graber and Graber (1983) found that birds moved

more at decreased larval density as they foraged. I observed increased searching activity only for the chestnut-sided warbler.

2) foraging in areas of lower deposit Movement from areas of higher deposit to areas of lower deposit was observed for the white-throated sparrow and the magnolia warbler. Chestnut-sided warblers, on the other hand, showed no movement within the canopy. Out of 8 species of foliage-gleaning birds, Greenberg (1983) found the chestnut-sided warbler to be the most specialized in its selection of microhabitats. This may explain the observed lack of movement by this species, and their increased searching activity, assuming that invertebrate populations would be more depressed in areas of higher insecticide deposit.

3) searching a larger area The area searched could be increased by foraging on a greater number of tree species. Behavioural changes imposed on a bird species that forages mainly on one insect species, in a limited number of tree species, should be more pronounced. Reports of increased tree species use (Hunter and Witham 1985) have involved budworm-associated bird species foraging mainly on one insect species (budworm), which was affected by the spray. In contrast, the Icewater Creek area lacked a dominant insect species. Consequently, an increase in tree species use was less probable. There was, however, a trend for birds in the treated area to forage in more tree species.

C. Long-term population trends

In examining the consequences of pesticide applications on forest songbird populations, it is important to know how changes within one season compare to longer population trends. During 1983 to 1987, bird populations in the study area seem to have been decreasing overall (Figure 1.2). There have been no other long-term studies of bird populations in Northeastern Ontario. But studies conducted in Northwestern Ontario (Black Sturgeon Lake) (Kendeigh 1947; Sanders 1970; and more recently, D. Welsh pers. comm.⁷) suggest that populations of budworm-associated species have followed cycles of budworm populations with a delay of 1 or 2 breeding seasons. Populations of the Icewater Creek area have responded to decreases in budworm populations of the Northeastern district of Ontario (Table 1.4). The 1986 budworm situation contrasts that of 1982 and differs markedly from the outbreak situation of 1980.

Some species of birds increase in numbers in response to increases in budworm numbers (MacArthur 1958; Morris et al. 1958; Crawford and Jennings 1982). Density of these species can increase from 5 to 9 pairs per hectare. Other birds show an inverse response. In decreasing budworm populations this pattern is reversed (Sanders 1970). The observed change of 2.5 birds per hectare (1.3 pairs) on plot C was low compared to that reported

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by Morris et al. (1958; 7.5 pairs). His result was over a 10 year period; covering an 8,000 fold change in budworm populations. Although the outbreak Morris (et al. 1958) studied was less severe than that preceding my study (Kettela 1983), budworm numbers had declined before my censuses were initiated. Therefore, fluctuations in budworm numbers were probably less pronounced during my study. Nonetheless, it is reasonable to assume that budworm populations affected bird populations at Icewater Creek in the appropriate habitat. The lack of response on plot T may have been due to: a) a masking effect of the treatment; b) the marginal habitat for budworm, and therefore, budworm-related species of birds; or c) any change relative to budworm may have occurred before my study began.

Yearly fluctuations may also be related to habitat changes. Decreases were noted in the ovenbird, chestnut-sided warbler, common yellowthroat, and the white-throated sparrow, but there were no corresponding increases in other species to suggest that a change in habitat composition, favouring one species over another, occurred. Census results show a decrease in the number of species, from a mean of 33 in 1983 and 1984, to a mean of 26 in 1986 and 1987. Species not recorded in later years were uncommon to the area, either nesting at the edge of their range (great-crested flycatcher, wood thrush, and Wilson's warbler), or in marginal habitat (red-breasted nuthatch, solitary vireo). Numbers of these species may have peaked prior to this study with individuals possibly occupying less suitable territories. A

reduction due to habitat change is unlikely.

The population trends on plots T and C indicate that pesticide treatment caused medium-term behavioural changes that affected breeding success through: 1) a lower proportion of young fledged on the treated plot during the year of treatment; and 2) a reduced recruitment of individuals the year following the treatment. The proportion of fledglings and males captured in mist nets was also lower than that reported by Lehoux et al. (1982); $\bar{x} \pm SE = 27.4 \pm .3$ fledglings and $\bar{x} \pm SE = 43 \pm .3$ males. These medium-term effects did not result in an overall change in abundance. Population trends were influenced more by environmental factors other than treatment.

D. Exposure

Differential impact on canopy-feeding birds compared to ground-feeding birds (Moulding 1976; Pearce and Peakall 1977; Peakall and Bart 1983) suggests a relationship between exposure and effect, however, it does not establish the cause to be a decreased abundance of food as Hunter and Witham (1985) have proposed. Areas of increased deposit have more potential for direct dermal exposure as well as greater indirect effects through decreased food available. The magnolia warbler feeds almost exclusively on coniferous insects, and are therefore, at greater risk from applications directed at a coniferous pest such as budworm. In the present study, the magnolia was the only

indicator species to decrease its use of conifers after both applications.

Chestnut-sided warblers forage in deciduous trees which received, in 1986, less deposit than the coniferous trees utilized by the magnolia warbler and the white-throated sparrow. Magnolia warblers were less visible after the application (Figure 1.7), and white-throated sparrows moved from locations of high exposure to a lower exposure (Figure 1.8). Chestnut-sided warblers on the other hand, were more visible following the 1986 application (Figure 1.6). Yet in 1985, when deciduous trees received as much deposit as the conifers, chestnut-sided warblers did not increase their activity.

Although deposits were lower in deciduous trees following the 1986 application, behaviour changes were more apparent. This may be due to the insufficient immediate postspray samples in 1985, but it may also be due to the difference in area treated. In 1986 with only 3 ha treated, birds were perhaps able to forage outside the spray block without having to travel far from their territories. In 1985 however, with a larger area treated (49 ha), the option to forage outside the spray block was less available. The energy expended to increase foraging distance might not compensate for the increased energy intake. The larger block size in 1985 may have resulted in reduced reproductive success as observed after this application only.

Hunter and Witham (1985) observed no change in the number of warblers foraging or their foraging niche on a treated area, relative to a control, when the entire area was treated. However, when only 30 percent of the area was treated, behavioural changes were observed. The difference, they proposed, was that with complete coverage, birds don't have the opportunity to shift their foraging area. Presumably, these birds would have to make do. The expected effect would be a lower breeding success due to less food available, but no change in foraging location. Whereas with spray refuges, the expected result would be behavioural changes to compensate, and little or no change in reproductive success.

CONCLUSION

The main results of this study are: 1) when birds cannot easily forage in unsprayed areas (e.g. in 1985, and most operational sprays), their fledging success is decreased (Table 1.5); and 2) they return at a lower rate the following year (Table 1.5). However, when birds can easily forage in unsprayed areas nearby as in 1986, fledging success is unaffected.

Behavioural changes were mainly confined to feeding behaviour. These changes were unrelated to overall population trends, but they indicate how insecticide sprays affect forest songbirds, and should therefore be included in a monitoring method. The method described here requires considerable expertise

but is sensitive and nondestructive.

Long-term populations trends were unaffected by treatment. At 280 gAI/ha, fenitrothion appears to have little effect on forest songbirds. For an indication of long-term population trends, a census program with territory mapping could provide an adequate measure of population changes if carried out over enough locations to control for environmental factors such as habitat differences, and weather effects.

EFFECTS OF FENITROTHION ON THE TERRESTRIAL INVERTEBRATE
FOOD OF FOREST SONGBIRDS

INTRODUCTION

Chemical insecticides are indiscriminate killers of terrestrial arthropods; affecting both target and nontarget species. One such insecticide, fenitrothion, is commonly used for control of spruce budworm (Choristoneura fumiferana (Clem.)) and hemlock looper (Lambdina fiscellaria fiscellaria (Guen.)) in Eastern Canada (Anon. 1987), and pine beauty moth (Panolis flammea D. and S.) in Scotland (Spray et al. 1987). When used in forest insect control operations, the direct effects of fenitrothion generally last from 2 to 5 days, when large numbers of nontarget invertebrates are killed (Varty 1974; Varty 1977). Residual levels of fenitrothion, (up to 10% of the initial deposit), may remain available to defoliating insects up to 30 days after application due to accumulation in the foliage (NRCC 1975).

Insects are the principal food of forest songbirds, and as such, a reduction in the abundance of insects might adversely affect songbird populations. Spruce budworm larvicides like fenitrothion are applied during the breeding season of forest songbirds, at a time when a depletion of available food should be critical. During the breeding season, even the young of

seed-eating birds may require insects in their diets.

Birds respond to a decrease in insect abundance with a change in foraging strategy or emigration from the area (Macdonald and Webb 1963; Doane and Schaefer 1971; Moulding 1976; Bart 1979; Hunter and Witham 1985). Insecticide-induced decreases in insect abundance have resulted in fewer warblers feeding in sprayed areas (Hunter and Witham 1985; Doane and Schaefer 1971). In addition, those warblers which continued to forage in the sprayed areas utilized more tree species, and decreased their use of spruce. Such changes in foraging behaviour might reduce foraging efficiency.

Most warblers eat all major orders of arboreal arthropods but select food of greater biomass yield or caloric value per unit of feeding time (MacArthur 1958). Lepidopteran larvae, the target insects in most control operations, are the preferred food for meeting the high energy demands of young birds (Royama 1970; Knapton 1984).

Under conditions of low food abundance, a greater range of food items will be taken (Schoener 1971). When insects become scarce, birds can find and consume only a small portion of the food available due to increased efforts required to locate widely spaced items (Kendeigh 1947). Both mean hunting time per item, and travelling time between patches of prey, should increase (Schoener 1971). It is likely therefore, that a spray-induced

reduction in prey availability would affect the foraging efficiency of forest songbirds.

Deposit of sprayed chemicals in the forest canopy is uneven both horizontally and vertically (Armstrong and Yule 1978; Spillman and Joyce 1978; Barry 1984). Hence, effects on the invertebrate community are also uneven (Varty 1974). Exposure to aerial insecticides is greatest in the crown of the trees where the largest deposits occur (NRCC 1975). This differential deposit results in differences in insect abundance at various canopy levels and may cause increased effects on canopy feeding bird species (Moulding 1976, Hunter and Witham 1985). The potential for effects on forest songbirds, through a depletion of food, would therefore depend on the canopy region in which the birds feed, and the depletion of food available in that niche.

The objectives of this study are: a) to determine if the application of fenitrothion causes a change in relative abundance of invertebrates, and hence, a change in food available to forest songbirds; b) to determine how this change is related to the amount and spatial location of insecticide deposited; and c) to determine the duration of any reduction in invertebrate numbers.

METHODS

To measure the effect of spraying with fenitrothion on the

birds' food source, samples were taken to determine a) changes in insect abundance on sprayed trees; and b) the quantity of food (insects) removed from the trees by spraying. This study was conducted in 1986 when a ground application was used to simulate an aerial spray; details of the application are given in Chapter 1.

The two most common tree species in the area, and those most frequently used by the bird species of interest, were balsam fir and white birch. Nine sample trees of each species were selected in the treatment area, and in the untreated control area. All trees were between 6 and 8 meters in height. A detailed habitat description is given in Chapter 1.

A. Changes in insect abundance on sprayed trees:

To measure the change in relative abundance of invertebrates on sample trees, branch samples were collected by pole pruning before and after the application. This technique has been utilized extensively for spruce budworm population studies, and to determine the spray efficacy of insecticide applications (Morris 1955; Sanders 1980). To adapt this method for my study, all invertebrates were collected from the branches rather than just the target insects. Samples were taken 13 June (5 days before the application), 20 June (2 days after the application), 23 June (5 days after the application), and 3 July (15 days after the application).

Measurements of residue taken following the aerial application in 1985 confirmed the expected concentration of chemical deposit in the upper canopy region (Table 1.1). Conifer crowns received approximately 2.5 times the concentration of the deposit received on inner foliage or on outside foliage of the lower canopy region. White birch foliage however, did not intercept the deposit in the same way, probably due to the differing geometry of the 2 tree species. Nonetheless, a lateral stratification of deposit still occurred where the inner foliage received less chemical than outside foliage for the same canopy region.

For this reason, some differential effect on insect abundance would be expected for both species of trees. Branches were randomly chosen from 5 separate canopy regions to measure this differential effect. The regions were identified as top (0-2 m from the crown tip), mid-outside (a 46 cm branch tip 2-4 m below the crown tip), and mid-inside (the next 46 cm of the same branch), lower-outside (greater than 4 m below the crown tip), and lower-inside (the next 46 cm of the same branch) (Figure 2.1). Each sample was put in a separate paper bag and stored in a cold room where the insects could be kept alive but torpid until the branches were picked. Insects were removed from the branches using the method developed by Deboo et al. (1973). All invertebrates were picked from the branch samples within a week of collection. Invertebrate samples were preserved in a solution of 70 percent water, 28 percent methanol and 2 percent glycerin.

Figure 2.1. Diagrammatic representation of balsam fir and white birch sampling regions. O=outside, I=inside, m=meters.

They were later counted and identified to family.

Samples were taken for analysis of residues from the same canopy regions, to relate changes in insect abundance to insecticide deposit.

Although the length of branch was constant for all samples, the number of buds (balsam fir) or leaves (white birch) varied considerably (CV = 58% for white birch, and 57% for balsam fir). Generally, fewer buds or leaves were found on the inside branches (about two thirds the number found on top branches). As the abundance of new growth may influence the abundance of resident arthropods (Varty 1977), I tested for a relationship between the number of new buds/leaves and the number of feeding insects. I found no definite relationship for either tree species on either plot. I therefore, did not correct for the number of buds or leaves.

All samples were also converted to biomass to better relate numbers of invertebrates to the amount of food available to birds. Results are presented for both numbers of invertebrates and sample weights. Samples were rinsed 3 times for 3 days each in 70 percent alcohol to remove any glycerin residues that may have penetrated the insects after storage in the 2 percent glycerin - alcohol solution. These samples were then oven dried at 50°C to constant weight. Food abundance was then expressed as mg dry wt per 46 cm branch.

B. Abundance of invertebrates in drop trays below sprayed trees:

To measure the quantity of insect food falling from the trees after the spray, nylon-screened drop sheets (1/4 m x 1/4 m) were placed under the foliage tips of each sample tree (Figure 2.2). These trays were raised about 20 cm above the ground to reduce predation on the killed invertebrates. Invertebrates were collected daily. Drop samples were treated (i.e. preserved, counted, and identified) in a manner similar to branch samples.

RESULTS

Relative abundance and distribution of invertebrates:

Thirty-two families were identified from branch samples of balsam fir and 31 from white birch. The most common invertebrates in both treated and untreated control areas, were either sucking plant feeders (Homoptera), foliage feeders (Lepidoptera, Hymenoptera, Coleoptera), or browsers of lichen or pollen (Psocoptera, Coleoptera). Invertebrates feeding upon the trees (feeders) were distinguished from those that merely perched (non-feeders) and sought prey (predators) on the trees. The distribution of these three groups of invertebrates among canopy regions, was similar for treatment and control trees (for example, Figure 2.3). The feeders were present over all canopy regions, but were less common on inside branches of white birch. Predatory invertebrates (mainly Araneida and Hemiptera) were more

Figure 2.2. Diagrammatic illustration of the placement of invertebrate drop trays under the foliage tips of balsam fir and white birch.

Figure 2.3. Distribution of invertebrates (F=feeders, N=nonfeeders, p=predators) in the 5 canopy regions, on treatment and control white birch trees. These samples were taken before the application.

common on balsam fir than on white birch. On balsam fir they were found throughout the tree, but on white birch they were most commonly found on the inside branches. Nonfeeding invertebrates (mainly Diptera) were only infrequently collected in branch samples.

Samples included both adult and immature forms; pupae and cocoons were eliminated from analysis. In families where feeding habits changed with development of the insect, they were separated accordingly. Consequently, "feeders" include both adult and larval invertebrates.

Effect of Treatment:

A. Branch samples

To address the question of an effect of deposit on total food availability, I first tested for an interaction between zone (areas of higher and lower deposit) and time (postspray verses prespray). An analysis of variance was conducted on log transformed numbers of invertebrates, using the model: $\log(N+1) = \text{tree} + \text{time} + \text{zone} + \text{tree} * \text{time} + \text{zone} * \text{time} + \text{tree} * \text{zone} + \text{tree} * \text{time} * \text{zone} (\text{error})$. For balsam fir, the results indicated a significant natural decrease over time ($p = .01$ for control trees), with a more pronounced reduction over time in the treated area ($p < .001$). More variation in the control area was between trees than between times, zones, or the interaction of these ($p < .001$).

In the treated area, most variation occurred over time. The interaction between zone and time was only significant in the treated area ($.02 < p < .05$) indicating a treatment effect. However, the zones of greatest reduction were not consistently the zones of highest deposit, suggesting no relationship between the amount of deposit and reduction of insects in the tree.

Results for white birch indicated a significant natural change over time on both plots ($p < .001$ for control; $p = .001$ for treatment). The only time period significantly different on treatment from control ($p < .05$, t-test, $df=64$) was 5 days after the application, when control numbers increased 2 fold from previous samples, with no corresponding increase on treatment. There was a significant effect of zone on both plots ($p < .001$ for control; $p = .002$ for treatment), where invertebrates were more abundant in the outside canopy regions, but no significant interaction between zones and time for either treated or control trees. Variance between trees was highly significant for control ($p < .001$) but not significant for treatment.

Fenitrothion residues were less stratified in white birch than in balsam fir. Deposit received in top, mid-outside and lower-outside branches was 1.3, 1.5 and 1.1 times, respectively, that received on inside foliage (Table 1.1). The areas where deposit concentrated were those where biomass decreased most. There was a significant decrease over time in both areas of higher deposit ($p < .001$) and areas of lower deposit ($p < .01$), but

the regression was only significant for areas of higher deposit ($p < .05$, $df=33$)).

Some trees had many more invertebrates than others (for example, the average number of invertebrates before spraying on balsam fir tree 1 was about 3 times that on tree 4). I therefore analyzed percent population change by tree, then calculated the mean of these 9 values for each plot and each tree species. Considering feeders only, the mean percent population reduction on balsam fir was 30% five days after the application, and a further 25% fifteen days after spraying (Table 2.1). The corresponding natural mortalities on the control plot were 0 and 13 percent respectively. The overall population reduction was 48% on treatment and 9% on control. Cadogan (1986) reported a reduction of 67 to 84 percent with fenitrothion applied twice at 210 g AI/ha, and a control mortality of 0 to 33 percent. His numbers referred only to spruce budworm.

Trends on white birch were similar in the treated and untreated areas, although there was considerably more variation over time in control trees (Table 2.1). Numbers of invertebrates collected before spraying and 3 days after the spray were similar in treated and untreated samples. However, large increases (T2 to T3; between 3 and 5 days after the application) in the number of invertebrates sampled from trees 1, 4 and 7 on control, followed by equally large decreases (T3 to T4; between 5 and 15 days after the application) made the analysis difficult to interpret. The

Table 2.1. Changes in the relative number of invertebrates $((T_{i+1}-T_i)/T_i)$, where T_i is the time period i) collected from each sample tree, from before the application to 15 days after the application. T_1 = before spraying; T_2 = 3 days after spraying, T_3 = 5 days after spraying, and T_4 = 15 days after spraying.

	TREATMENT			CONTROL		
TIME PERIOD	T1-T2	T2-T3	T3-T4	T1-T2	T2-T3	T3-T4
BALSAM FIR:						
TREE						
1	0.35	-0.80	-0.27	-0.41	0	-0.56
2	1.36	-0.35	-0.82	0.29	-0.36	-0.55
3	-0.71	-0.33	-0.58	4.50	-0.27	-0.38
4	0.75	-0.64	0.20	-0.67	1.83	1.29
5	-0.46	0.86	-0.92	0.33	-0.43	-0.69
6	-0.14	0.13	-0.33	0.79	-0.48	-0.04
7	0.17	-0.80	0.67	0.47	-0.57	0.50
8	0.47	-0.13	-0.43	-0.42	0.39	0
9	0.61	-0.64	0.25	-0.10	0.32	-0.78
$\bar{x} \pm SE$	.27 $\pm$.21	-.3 $\pm$.18	-.25 $\pm$.18	.62 $\pm$.51	.14 $\pm$.25	-.13 $\pm$.22
overall change: $\bar{x} \pm SE$	= -.48 $\pm$.17			$\bar{x} \pm SE$ = -.09 $\pm$.29		
WHITE BIRCH:						
TREE						
1	-0.19	-0.79	0.18	0.36	3.00	-0.63
2	0.04	1.52	-0.87	-0.07	0.39	-0.44
3	2.08	-	-0.70	-0.42	2.29	-0.57
4	-0.08	-0.18	1.33	0.22	8.36	-0.90
5	0.67	-0.24	-0.11	-0.59	1.23	-0.35
6	-0.05	0.67	-0.73	-0.53	0.33	-0.20
7	0.53	-0.22	-0.17	0.91	2.48	-0.83
8	-0.24	-0.06	-0.40	-0.29	1.25	-0.80
9	-0.33	1.62	-0.94	2.12	0.26	-0.92
$\bar{x} \pm SE$	.27 $\pm$.25	.29 $\pm$.31	-.11 $\pm$.25	.19 $\pm$.29	2.18 $\pm$.84	
overall change: $\bar{x} \pm SE$	= -.30 $\pm$.18			$\bar{x} \pm SE$ = -.17 $\pm$.18		

overall percent population reduction from prespray to 15 days after was 30% on treatment and 17% on control, but the confidence intervals of these two values overlap.

If the insects were killed but remained on the branches, any effect of spraying would be visible only as a decrease in the proportion of living insects in each sample. The proportion of live insects was not reduced by 3 days after the application (Figure 2.4). This suggests that a large proportion of the insects not removed from the tree, remained alive for up to 3 days after the application. However, by 5 days after treatment the majority of insects remaining on the branches were dead. Any insects alive at sampling were kept alive. There was a significantly lower proportion of living insects on branches between prespray and 5 days after the application on the treated plot (a 10% reduction per sample period; $p < .005$, regression, $df=133$) but not on control. A steeper reduction occurred on the treated plot ($p < .001$, ANCOVA, $df=266$). Dead insects would not be available to birds that require movement to detect their prey. Greenberg (1983) found that warblers were not interested in mealworms as food unless these prey were alive. Increases in the proportion of live insects 15 days after the application (Figure 2.4) may have been due to a removal of dead insects from the tree, or to the movement of live insects within the tree.

The proportion of live insects in white birch branch samples was unaffected by the treatment (Figure 2.4). Insects not removed

Figure 2.4. Comparison of the proportion of invertebrates ($\bar{x} \pm SE$) collected from branches that were alive at different time periods (before (T₁), 3 days after (T₂), 5 days after (T₃), and 15 days after (T₄), the application), on treated and control sample trees (balsam fir and white birch).

from the tree would therefore be suitable as prey for birds like warblers that select living insects.

Changes in relative abundance may be unrelated to the amount of energy available to birds. Analysis of changes in dry weights of food available on balsam fir suggest a significant decrease in biomass of invertebrates on treated trees ($p < .001$, regression, $df=33$) and control trees ($p < .01$, regression, $df=32$). This reduction was not restricted to the canopy regions receiving higher deposit.

Biomass calculations from white birch show a significant ($p < .001$, regression, $df=33$) decreasing trend in the amount of invertebrate food available following treatment. In contrast, the control results show an increasing trend over the same time period ($p < .05$, regression, $df=33$).

B. Drop tray samples

The drop tray samples from balsam fir suggest that fenitrothion had an immediate effect on Diptera and Hymenoptera, and an extended effect on feeders (Figure 2.5). This agrees with the NRC (1975) report on fenitrothion which found the peak kill for Diptera to be 2 days earlier than that of defoliators. The abundance of dead insects was highest 1 day after the application, falling off to baseline levels by 4 days after spraying (Figure 2.6). This suggests an exponentially decreasing

Figure 2.5. Proportion of Diptera, Hymenoptera, and feeders in drop tray samples taken 1 to 3 days after the application, from balsam fir ($\bar{x} \pm SE$) of 9 sample trees).

mortality rate, with the greatest kill occurring almost immediately.

Results for white birch again show a large immediate kill of invertebrates (Diptera, Hymenoptera and feeders) with some extended kill (mainly feeders) up to 3 days after the application (Figure 2.7, Table 2.2).

Table 2.2. Proportion of Diptera, Hymenoptera, and feeders in drop tray samples from white birch trees ($\bar{x} \pm SE$ of 9 sample trees).

DAYS AFTER THE APPLICATION	+1	+2	+3
Diptera	.25 $\pm$.07	.21 $\pm$.08	.30 $\pm$.11
Hymenoptera	.18 $\pm$.05	.19 $\pm$.08	.09 $\pm$.04
feeders	.55 $\pm$.11	.62 $\pm$.10	.53 $\pm$.11

There was no apparent relationship between the increased number of invertebrates that dropped onto trays and the reduced number of invertebrates in the branches for either tree species (Table 2.3). Although the birch tree with the largest drop was the tree with the biggest change in insect numbers, this does not apply for the birch tree with the next larger drop.

DISCUSSION

My results from drop trays below white birch were similar to Fraser's (1983) results following an application of fenitrothion at 210 g/ha. His found a 30.5 $\pm$ 7.37 ($\bar{x} \pm SE$) % kill of all invertebrates compared to my 42.4 $\pm$ 15.49. In Fraser's study, the

Figure 2.6. Abundance of invertebrates collected from drop trays below balsam fir ($\bar{x} \pm SE$ of 9 sample trees; $1/4m^2$ sampler) on treatment and control.

Figure 2.7. Abundance of invertebrates collected from drop trays below white birch ($\bar{x} \pm SE$ of 9 sample trees; $1/4m^2$ sampler) on treatment and control.

Table 2.3. Relationship between branch and drop tray samples using the proportion of prespray invertebrates surviving to 5 days after the application (T_3/T_1), compared to the cumulative number of invertebrates collected from drop trays 1, 2, and 3 days after treatment. This number was then expressed as a proportion of the average number before spraying $((N_1+N_2+N_3)/N_{pre})$.

	PROPORTION SURVIVING (T_3/T_1) ON BRANCHES	CUMMULATIVE DROP $((N_1+N_2+N_3)/N_{pre})$
BALSAM FIR:		
TREE		
1	0.28*	14.4
2	1.00	14.5
3	0.86	27.9**
4	0.63	18.0
5	1.00	27.9**
6	1.00	14.7
7	0.17*	15.0
8	0.47	33.8**
9	0.14*	11.7
WHITE BIRCH:		
TREE		
1	0.17*	62.0**
2	1.00	54.8**
3	0.92	12.6
4	0.75	17.2
5	1.00	9.2
6	1.00	7.5
7	1.00	18.3
8	0.71*	8.2
9	1.00	2.8

* largest reduction in number of invertebrates per branch

** largest cummulative drop

corresponding kill of budworm was 22.5 % and he found a similar species composition in his branch and drop tray samples. I know of no comparable studies for balsam fir.

The numbers of insects falling onto drop trays suggests a larger effect than that measured by branch sampling. Although the same trees were used for both drop tray and branch sampling, the two methods were not strictly comparable. This is due to the predominance of Diptera in the trays and their scarcity on branch samples. Branch samples were composed of mostly invertebrates associated with the tree. Consequently, the two sampling procedures selected quite different organisms. Table 2.4 lists the proportion of the major insect groups found in branch samples before spraying, and immediately (1 to 3 days) after spraying in drop trays. The removal of large numbers of Diptera probably had little effect on the insect population of the tree. Drop trays under white birch sampled a greater number of feeders than balsam fir drop trays, and there was some correspondence between the effect on branches and the drop sample results, whereas, no correspondence was found on balsam fir.

For any particular tree, the number of insects in drop trays was not a good predictor of changes in the invertebrate population on its branches. The magnitude of drop may have depended on whether the branches above the tray received a heavy deposit or not. The number of branches sampled by the drop trays was not known, but the trays remained in the same place

Table 2.4. Comparison of the invertebrate composition of branch samples to that of drop tray samples.

	PROPORTION OF BRANCH SAMPLES ¹	PROPORTION OF DROP TRAY SAMPLES ²
BALSAM FIR:		
Diptera	.03	.45
aphids	.37	.27
Hymenoptera	.03	.15
spiders	.14	0
Coleoptera	.05	.06
Lepidoptera	.01	.01
feeders	.76	.39
WHITE BIRCH:		
Diptera	.01	.22
aphids	.40	.45
Hymenoptera	.03	.15
spiders	.02	0
Coleoptera	.17	.03
Lepidoptera	.02	.03
feeders	.95	.59

¹ calculated as a proportion of the prespray total number of invertebrates.

² calculated as a proportion of the total drop from 1, 2, and 3 days after the application.

throughout the study. For branch sampling, however, a different branch was randomly selected each time. Branches were never taken from the foliage column above the drop tray (to prevent sampling disturbance of the invertebrates). Thus, deposit on the branches above the drop tray could have differed significantly from that on the branches taken for analysis of invertebrate population changes.

Variability between branch samples, due to the patchy nature of insecticide deposits, could also explain the discrepancy between the magnitude of drop from trees and the reduced number of invertebrates on their branches. By randomly selecting branches, one sample could have had a different level of deposit than another. Branches receiving little deposit could mask an effect on neighbouring branches receiving more deposit.

From this study and others (Varty 1977), it is apparent that refuges of unsprayed foliage (such as the inside foliage or the downwind side of the tree) exist in any spray block, and a proportion of any invertebrate species' population is likely to avoid contact with the chemical (Varty 1977). This is why control of the target, spruce budworm, is incomplete (70-80%, Varty 1977). Mobile arthropods tend to invade empty niches, and recuperation is generally rapid. Varty (I.W. pers. comm.⁸) used a permethrin wash to measure the insect population remaining in

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balsam fir trees after a double application of 210g AI/ha of fenitrothion. He found no significant spray impact on the aphid population despite a large kill of aphids onto the drop trays. Therefore, unless birds feed only in highly exposed regions of the tree, they should be able to find refuges of insects within their territory or close by. This may require a change in foraging site, but not for all individuals, and this may significantly dampen any effect of treatment on reproduction or survival.

Differences in invertebrate kill between canopy regions were not marked, nor was there a strong relationship of kill to deposit of fenitrothion; in balsam fir, there was no indication that increased deposit had an increased effect on the invertebrates. This result may be a consequence of an inadequate sampling intensity. Nevertheless, because spray is deposited unevenly over individual trees, some variability in effect is inevitable.

Branch sampling provided an adequate index of population changes on treated and control trees. The initial invertebrate population on the tree could not, however, be determined. Branch sampling did not provide an accurate measure of the total invertebrate population due to the uneven distribution of the invertebrates and the subsequent variability between branches. A preferable design would be to supplement sample trees with a known population of budworm, for example, in order to accurately

determine the magnitude of effect on the invertebrate population of the tree.

Despite these problems, the results obtained in this study agree with those reported elsewhere. Fenitrothion has been found to cause a large, immediate (within the first 4 days) kill of larval Lepidoptera, sawfly larvae, aphids and perching flies; Dipterans are killed directly after the spray (Sumitomo 1978; Fraser 1983). Buckner (1974) proposed that prolonged mortality of feeders might occur following fenitrothion treatment, and that this could be attributed to differing exposure routes (contact verses ingestion). The opportunity for exposure through contact decreases rapidly after the application, whereas poisoning by ingestion may be prolonged through the progressive concentration of toxins.

CONCLUSION

The fenitrothion treatment in 1986 killed mainly Diptera (in the drop tray results), and feeding invertebrates (in both drop trays and branch samples). There was, however, little effect on the total invertebrate community of either balsam fir or white birch. Since there was no dominant insect species in the area I expected birds to forage approximately equally on all available insect groups. There may have been a slight reduction in food availability, but this reduction would have been short-lived if insects moved in from unsprayed areas nearby. Furthermore, if

this reduction in food availability was of surplus food, there would be no effect on breeding success.

GENERAL DISCUSSION

Applications for spruce budworm have continued for 30 years, over millions of hectares of forest, yet budworm continues to be a problem. Those budworm not contacted by the spray (20-30 % of the population), survive to increase the population the following year (Prebble 1950; Varty 1977). Annually repeated applications are therefore necessary to protect the new foliage (Grimble and Morris 1983). Repeated use of insecticides could cause additional stress on songbird populations, beyond that measured in my study, through a continued reduction of food available or continued effects on reproductive success. Large-scale (100-1000 ha) spray blocks could also increase the potential for effects on birds by limiting: 1) the movement of birds to feed outside the treated area, and 2) immigration of invertebrates into the sprayed area. The effect on food availability to birds would therefore be enhanced in operational sprays of this scale.

Under operational conditions, fenitrothion is typically applied twice at 210 gAI/ha with a 5-6 day interval. In this experiment, fenitrothion was applied once at 280 gAI/ha. A double application may impact more heavily on the invertebrate community by reaching those invertebrates not contacted with the first application; thereby further reducing the total invertebrate community of the tree. This may explain the relatively low impact observed on the invertebrate community (compared to mortalities reported by Cadogan (1986), for example), and in turn, the slight

response from forest songbirds. At the maximum allowable single dose, fenitrothion appears to have little effect on forest songbirds, even when tested with a highly-sensitive method.

The method described in this thesis was developed specifically to answer an important, but unresolved, question in forest pest management: What are the medium and long-term, sublethal effects of chemical insecticides on forest songbird populations? The results suggest that at least some of the techniques used could be adapted for monitoring programs at the operational level, and for candidate insecticide screening in small scale field trials. There is no reason to restrict the method to chemical insecticides that directly, though inadvertently, poison birds. Even biological insecticides (B.t. or viruses), which are much more pest specific, can affect birds through a reduction of the food base required for maintenance and reproductive success. The method described should detect this impact. On the whole, the monitoring method used in this study, should provide a sensitive measure of the impact of insecticides, chemical or biological, on forest songbird populations.

Even though the method is adaptable, a major problem remains that is characteristic to any monitoring program. The study area may not be representative of other spray areas (receiving the same application), due to variability in: habitat, phenology, amount of spray deposited, and the bird population. Even within a sprayed area, there is a problem of variability in deposit. Due

to the uneven deposit, and the resulting uneven effect on invertebrate food of birds, variability in response to the application of an insecticide such as fenitrothion is inevitable. This is the nature of the beast, and is precisely why control of eastern spruce budworm has not been possible.

It is likely that in any forestry application of insecticides (due to variable wind conditions, structure of the forest, and micrometeorological conditions at the time of spray), some individual birds will receive little exposure while other individuals, occupying the same niche, could receive more. Consequently, the average response will likely be dampened by birds less exposed to the insecticide. This variability in potential effect cannot be improved by increased sample size. (Increased sample size would, however, control for variability of response among individuals exposed to the same deposit.) The average effect is all that can be achieved. With this in mind, measurable changes in bird behaviour, and the bird population, should not be underestimated as these effects would undoubtedly be dampened.

To understand how insecticide applications affect birds, less emphasis should be placed on ChE inhibition itself. For ChE inhibition to be meaningful, it must be coupled with behavioural responses to that inhibition. With the current move to biological insecticides, it is even more critical that an alternative method be developed.

The impact of insecticides on forest songbirds is a highly complex problem which may be better approached through controlled experiments where a known deposit is applied on all locations of the tree with a known initial population of invertebrates. This would provide a more accurate measure of changes in food availability and how this affects behaviour. This is the direction I would like to pursue.

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APPENDIX I

HABITAT ANALYSES

Table 1. Habitat analysis of plot T, 1984.

Number of circles = 12

TREES:		DENSITY ¹									
		Number of trees in all circles by diameter of size class									
SPECIES		A	B	C	D	E	F	G	H ⁴	Total	Trees/hectare (by species)
		7-13.3	13.3-19.3	19.3-29.5	29.5-38	38-46	46-52.8	52.8-60.3	60.3		
<i>Betula papyrifera</i>		11	3	5	1					20	6.4
<i>Alnus rugosa</i>		3								3	1.0
<i>Abies balsamea</i>		27	6	1						34	10.9
<i>Acer rubrum</i>		1		1						2	0.6
<i>Acer saccharum</i>		1	1	2						4	1.3
<i>Fraxinus nigra</i>		1	1	2						4	1.3
<i>Thuja occidentalis</i>		13	21	32	4		1			71	22.7
<i>Taxa canadensis</i>		1								1	0.3
<i>Picea glauca</i>		4	2	1		1				8	2.6
<i>Prunus virginiana</i>		8								8	2.6
<i>Betula lutea</i>							1			1	0.3
<i>Populus tremuloides</i>		7	1							8	2.6
TOTALS		77	35	44	5	1	2			164	52.5
Trees/hectare (by size class)		25.3	11.2	14.1	1.6	0.3	0.6				
Relative density (by size class)		47	21.3	26.8	3.0	0.6	1.2				
TREES:		BASAL AREA ⁵								FREQUENCY ⁸	
		Cross sectional area of the trunk at breast height (d.b.h.)								Total basal area (by species sq m)	Relative dominance ⁷ (by species)
SPECIES		A ⁶	B	C	D	E	F	G	H		
		(.009)	(.027)	(.072)	(.162)	(.279)	(.441)	(.639)	(.0005 m ²)		
<i>Betula papyrifera</i>		.099	.081	.36	.162					.703	10.4
<i>Alnus rugosa</i>		.027								.027	0.4
<i>Abies balsamea</i>		.245	.162	.072						.477	7.0
<i>Acer rubrum</i>		.009		.072						.081	1.2
<i>Acer saccharum</i>		.009	.027	.144						.18	2.7
<i>Fraxinus nigra</i>		.009	.027	.144						.18	2.7
<i>Thuja occidentalis</i>		.117	.567	2.304	.648		.441			4.077	60.2
<i>Taxa canadensis</i>		.009								.009	0.1
<i>Picea glauca</i>		.036	.054	.072		.279				.441	6.5
<i>Prunus virginiana</i>		.072								.072	1.1
<i>Betula lutea</i>							.441			.441	6.5
<i>Populus tremuloides</i>		.063	.027							.09	1.3
TOTALS		.693	.945	3.168	.81	.279	.889		.522	6.778	100%
Basal area (by size class)		.558	.756	2.538	.648	.225	.702				
Relative basal area (by size class)		10.2	13.9	46.9	12.0	4.1	13.0				
SHRUBS:	Total shrub stems in all transects (2 per circle) x 1000, divided by the number of transects = 21,483 shrub stems per hectare (1289 stems)										
GROUND COVER:	Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 67.5% ground cover.										
CANOPY COVER:	Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 60.8% canopy cover.										
CANOPY HEIGHT (O.S./U.S.):	Average: 12/2 Range = 7-24/1-3										
NOTES:	Cutover & second growth O.S. = 30% dry overall, fallen trees as dead underbrush throughout U.S. = 40%										

¹ Number per unit area² Total trees counted = 0.32³ Relative density is the percent of the total number of trees which are the species in question⁴ Give estimated diameter⁵ Basal area is the cross sectional area of the trunk of a tree at 1.3 meters (dbh)⁶ Multiply the number of trees in all circles in size Class A times .009 (average area in square meters for this size class)⁷ Total basal area of the species x 100

Total basal area of all species

⁸ Frequency indicates the evenness of distribution of a species⁹ Number of circles in which the species occurred x 100
Total number of circlesMajor spp shrubs - *Acer rubrum*, *Abies balsamea*, *Picea glauca*, *Populus tremuloides*, *Prunus idaeus*, *Betula papyrifera*, *Sorbus americana*, *Prunus pennsylvanica*, *Pinus strobus*, *Corylus cornuta*, *Acer spicatum*, *Amelanchier* sp., *Sambucus* sp., *Lonicera* sp.

Table 2. Habitat analysis of plot C.

Number of circles = 6

TREES:		DENSITY ¹										
		Number of trees in all circles by diameter of size class										
SPECIES		A	B	C	D	E	F	G	H ⁴	Total	Trees/hectare (by species)	Relative density ³ (by species)
		7-13.3	13.3-19.3	19.3-29.3	29.3-38	38-46	46-52.8	52.8-60.3	60.3			
<i>Abies balsamea</i>		43	21	2	-	-				66	42.2	55.0
<i>Picea glauca</i>		11	6	8	-	-				25	16.0	20.8
<i>Betula papyrifera</i>		9	2	1	1	1				14	9.0	11.7
<i>Picea mariana</i>		2	4	3	-	-				9	5.8	7.5
<i>Pinus strobus</i>		-	1	1	-	-			1	3	1.9	2.5
<i>Prunus pennsylvanica</i>		2	-	-	-	-				2	1.3	1.7
<i>Acer rubrum</i>		-	1	-	-	-				1	0.6	0.8
TOTALS		67	35	15	1	1	-	-	1	120	76.8	100.0
Trees/hectare (by size class)		42.9	22.4	9.6	0.6	0.6	-	-	0.6			
Relative density (by size class)		55.8	29.2	12.5	0.8	0.8	-	-	0.8			
TREES:		BASAL AREA ⁵								FREQUENCY ⁸		
		Cross sectional area of the trunk at breast height (d.b.h.)								Total basal area	Relative dominance ⁷	No. of circles in which species occurred
SPECIES		A ⁶	B	C	D	E	F	G	H	(by species sq m)	(by species)	Relative ⁹ frequency
		(.009)	(.027)	(.072)	(.162)	(.279)	(.441)	(.639)	(.0005 d ²)			
<i>Abies balsamea</i>		.387	.567	.144	-	-			-	1.098	30.5	6
<i>Picea glauca</i>		.099	.162	.576	-	-			-	.837	23.25	5
<i>Betula papyrifera</i>		.081	.054	.072	.162	.279			-	.648	18.0	5
<i>Picea mariana</i>		.018	.117	.216	-	-			-	.351	9.8	3
<i>Pinus strobus</i>		-	.027	.072	-	-			.522	.621	17.25	3
<i>Prunus pennsylvanica</i>		.018	.0	-	-	-			-	.018	0.5	1
<i>Acer rubrum</i>		-	.027	-	-	-			-	.027	0.8	1
TOTALS		.603	.945	1.08	.162	.279	-	-	.522	3.600	100.1	-
Basal area (by size class)		.963	1.512	1.728	.261	.450						-
Relative basal area (by size class)		16.8	26.3	30.0	4.3	7.8	-	-	14.5	-	-	-
SHRUBS:	Total shrub stems in all transects (2 per circle) x 1000, divided by the number of transects = 30,333 shrub stems per hectare (910 stems)											
GROUND COVER:	Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 67.5% ground cover.											
CANOPY COVER:	Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 60.8% canopy cover.											
CANOPY HEIGHT (O.S./U.S.):	Average: 12/2 Range = 7-24/1-3											
NOTES:	Cutover & second growth O.S. = 30% dry overall, fallen trees as dead underbrush throughout U.S. = 40%											

¹ Number per unit area² Total trees counted x 0.64³ Relative density is the percent of the total number of trees which are the species in question⁴ Give estimated diameter⁵ Basal area is the cross sectional area of the trunk of a tree at 1.4 meters (dbh)⁶ Multiply the number of trees in all circles in size Class A times .009 (average area in square meters for this size class)⁷ Total basal area of the species

Total basal area of all species

⁸ Frequency indicates the evenness of distribution of a species⁹ Number of circles in which the species occurred
Total number of circles x 100Major spp shrubs - *Acer rubrum*, *Abies balsamea*, *Picea glauca*, *Populus tremuloides*, *Rubus idaeus*, *Betula papyrifera*, *Sorbus americana*, *Prunus pennsylvanica*, *Pinus strobus*, *Corylus cornuta*, *Acer spicatum*, *Amelanchier* sp., *Sambucus* sp., *Coniopsis* sp.

Table 3. Habitat analysis of plot T2.

Number of circles = 6

TREES:											
DENSITY ¹											
Number of trees in all circles by diameter of size class											
SPECIES	A 7-13.3	B 13.3-19.3	C 19.3-29.3	D 29.3-38	E 38-46	F 46-52.8	G 52.8-60.3	H ⁴ 60.3	Total	Trees/hectare (by species)	Relative density ³ (by species)
<i>Picea glauca</i>	13	2	3	-	-	-	-	-	18	11.5	18.2
<i>Pinus strobus</i>	-	-	-	-	-	-	1	-	1	0.6	1.0
<i>Thuja occidentalis</i>	1	1	1	2	-	-	-	-	5	3.2	5.1
<i>Abies balsamea</i>	22	10	-	-	-	-	-	-	32	20.5	32.3
<i>Acer rubrum</i>	3	3	1	-	-	-	-	-	7	4.5	7.1
<i>Prunus virginiana</i>	1	-	-	-	-	-	-	-	1	0.6	1.0
<i>Prunus pennsylvanica</i>	1	-	-	-	-	-	-	-	1	0.6	1.0
<i>Alnus rugosa</i>	2	-	-	-	-	-	-	-	2	1.3	2.0
<i>Betula papyrifera</i>	8	3	2	2	1	-	-	-	16	10.2	16.2
<i>Betula lutea</i>	-	-	-	-	1	-	-	-	1	0.6	1.0
<i>Populus tremuloides</i>	11	3	-	-	-	-	-	-	14	9.0	14.1
<i>Sorbus americana</i>	1	-	-	-	-	-	-	-	1	0.6	1.0
TOTALS	63	22	7	4	2	-	1	-	99	63.4	100%
Trees/hectare (by size class)	40.3	14.1	4.5	2.6	1.3	-	0.6	-			
Relative density (by size class)	63.6	22.2	7.2	4.0	2.0	-	1.0	-			
TREES:											
BASAL AREA ⁵											
Cross sectional area of the trunk at breast height (d.b.h.)											
SPECIES	A ⁶ (.009)	B (.027)	C (.072)	D (.162)	E (.279)	F (.441)	G (.639)	H (.0005 d ²)	Total basal area (by species sq m)	Relative dominance ⁷ (by species)	No. of circles in which species occurred
<i>Picea glauca</i>	.117	.054	.216	-	-	-	-	-	.387	11.0	5
<i>Pinus strobus</i>	-	-	-	-	-	.639	-	-	.639	18.2	1
<i>Thuja occidentalis</i>	.009	.027	.072	.324	-	-	-	-	.432	12.3	3
<i>Abies balsamea</i>	.198	.270	-	-	-	-	-	-	.468	13.3	6
<i>Acer rubrum</i>	.027	.081	.072	-	-	-	-	-	.180	5.1	3
<i>Prunus virginiana</i>	.009	-	-	-	-	-	-	-	.009	0.3	1
<i>Prunus pennsylvanica</i>	.009	-	-	-	-	-	-	-	.009	0.3	1
<i>Alnus rugosa</i>	.018	-	-	-	-	-	-	-	.018	0.5	1
<i>Betula papyrifera</i>	.072	.081	.144	.324	.279	-	-	-	.900	25.6	4
<i>Betula lutea</i>	-	-	-	-	.279	-	-	-	.279	7.9	1
<i>Populus tremuloides</i>	.099	.081	-	-	-	-	-	-	.180	5.1	2
<i>Sorbus americana</i>	.009	-	-	-	-	-	-	-	.009	0.3	1
TOTALS	.567	.594	.504	.648	.558	.639	-	-	3.51	100%	
Basal area (by size class)	.909	.954	.810	1.035	.891	1.026	-				
Relative basal area (by size class)	16.1	16.9	14.4	18.5	15.9	18.2	-				
SHRUBS: Total shrub stems in all transects (2 per circle) x 1000, divided by the number of transects = 25,500 shrub stems per hectare (765 stems)											
GROUND COVER: Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 96.7% ground cover.											
CANOPY COVER: Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 40.8% canopy cover.											
CANOPY HEIGHT (O.S./U.S.): Average: 12/2 Range = 11-15/3-5											
NOTES: Cutover & second growth O.S. = 31%											
dry overall											
Mixed stand U.S. = 48%											
1 Number per unit area											
2 Total trees counted x 0.64											
3 Relative density is the percent of the total number of trees which are the species in question											
4 Give estimated diameter											
5 Basal area is the cross sectional area of the trunk of a tree at 1.4 meters (dbh)											
6 Multiply the number of trees in all circles in size Class A times .009 (average area in square meters for this size class)											
7 Total basal area of the species / Total basal area of all species x 100											
8 Frequency indicates the evenness of distribution of a species											
9 Number of circles in which the species occurred / Total number of circles x 100											

Major 500 shrubs - *Alnus rugosa*, *Alnus serrulata*, *Betula papyrifera*, *Sorbus americana*, *Prunus pennsylvanica*, *Prunus virginiana*, *Abies balsamea*, *Thuja occidentalis*, *Acer rubrum*, *Acer spicatum*, *Acer saccharum*, *Populus tremuloides*, *Fraxinus pennsylvanica*, *Sambucus canadensis*, *Picea glauca*, *Cornus alternifolia*, *Amelanchier* sp., *Salix* sp., *Lonicera* sp., *Spiraea* sp.

Table 4. Habitat analysis of plot T, 1986.

Number of circles = 6

TREES:		DENSITY ¹											
		Number of trees in all circles by diameter of size class											
SPECIES		A	B	C	D	E	F	G	H ⁴	Total	Trees/hectare (by species)	Relative density ³ (by species)	
		7-13.3	13.3-19.3	19.3-29.5	29.5-38	38-46	46-52.8	52.8-60.3	60.3				
<i>Abies balsamea</i>		8	-	-	-	-	-	-	-	8	5.1	18.3	
<i>Betula papyrifera</i>		5	1	-	1	-	-	-	-	7	4.5	15.9	
<i>Picea glauca</i>		-	1	1	-	-	-	-	-	2	1.3	4.5	
<i>Thuja occidentalis</i>		-	3	7	2	-	-	-	-	12	7.7	27.3	
<i>Asar rubrum</i>		3	-	1	-	-	-	-	-	4	2.6	9.1	
<i>Pinus rigida</i>		4	-	-	-	-	-	-	-	4	2.6	9.1	
<i>Prunus pennsylvanica</i>		2	-	-	-	-	-	-	-	2	1.3	4.5	
<i>Populus tremuloides</i>		2	1	-	-	-	-	-	-	3	1.9	6.8	
<i>Sorbus americana</i>		2	-	-	-	-	-	-	-	2	1.3	4.5	
TOTALS		25	6	9	3	-	-	-	-	44	28.2	100	
Trees/hectare (by size class)		16.6	3.8	5.8	1.9	-	-	-	-				
Relative density (by size class)		59.1	13.6	20.5	6.8	-	-	-	-				
TREES:		BASAL AREA ⁵								FREQUENCY ³			
		Cross sectional area of the trunk at breast height (d.b.h.)								Total basal area (by species sq m)	Relative dominance ⁷ (by species)	No. of circles in which species occurred	Relative frequency ⁹
SPECIES		A ⁶ (.009)	B (.027)	C (.072)	D (.162)	E (.279)	F (.441)	G (.639)	H (.0005 d ²)				
<i>Abies balsamea</i>		.072	-	-	-	-	-	-	-	.072	4.6	2	33.3
<i>Betula papyrifera</i>		.045	.027	-	.162	-	-	-	-	.234	15.3	3	50.0
<i>Picea glauca</i>		-	.027	.072	-	-	-	-	-	.099	6.5	1	16.7
<i>Thuja occidentalis</i>		-	.081	.504	.324	-	-	-	-	.909	59.4	2	33.3
<i>Asar rubrum</i>		.027	-	.072	-	-	-	-	-	.099	6.5	2	33.3
<i>Pinus rigida</i>		.036	-	-	-	-	-	-	-	.036	2.4	1	16.7
<i>Prunus pennsylvanica</i>		.018	-	-	-	-	-	-	-	.018	1.2	2	33.3
<i>Populus tremuloides</i>		.018	.027	-	-	-	-	-	-	.045	2.9	2	33.3
<i>Sorbus americana</i>		.018	-	-	-	-	-	-	-	.018	1.2	2	33.3
TOTALS		.234	.162	.648	.486	-	-	-	-	1.53		-	-
Basal area (by size class)		.3744	.261	1.035	.774	-	-	-	-			-	-
Relative basal area (by size class)		15.3	10.6	42.4	31.7	-	-	-	-			-	-
SHRUBS: Total shrub stems in all transects (2 per circle) x 1000, divided by the number of transects = 23,600 shrub stems per hectare (708 stems)													
GROUND COVER: Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 91.7% ground cover.													
CANOPY COVER: Total pluses (+) recorded (20 sightings per circle) x 100, divided by the total number of sightings = 36.7% canopy cover.													
CANOPY HEIGHT (O.S./U.S.): Average: 9/4 Range = 2-15/2-6													
NOTES: Cutover & second growth O.S. = 8%													
dry overall, fallen trees													
as dead underbrush throughout U.S. = 40%													

¹ Number per unit area² Total trees counted x 0.64³ Relative density is the percent of the total number of trees which are the species in question⁴ Give estimated diameter⁵ Basal area is the cross sectional area of the trunk of a tree at 1.4 meters (dbh)⁶ Multiply the number of trees in all circles in size Class A times .009 (average area in square meters for this size class)⁷ $\frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$ ⁸ Frequency indicates the evenness of distribution of a species⁹ $\frac{\text{Number of circles in which the species occurred}}{\text{Total number of circles}} \times 100$

Major spp shrubs - *Pinus strobus*, *Abies balsamea*, *Asar canadense*, *Salix* sp., *Prunus pennsylvanica*, *Sorbus americana*, *Populus tremuloides*, *Fraxinus pennsylvanica*, *Lonicera* sp., *Prunus virginiana*, *Picea glauca*, *Betula papyrifera*, *Pinus strobus*, *Pinus rigida*, *Asar rubrum*, *Thuja occidentalis*, *Cornus alternifolia*

Table 5. Rough calculations of foliage volume for plot T, plot T2, and plot C.

	Size Class of Tree ¹			Total ⁴
	A	B	C	
Foliage volume/tree ²	9.82m ³	22.7m ³	34.0m ³	
Total foliage volume ³				
plot T	304	182	68	554
plot T2	344	272	102	718
plot C	530	613	340	1483

¹ see Appendix I, Tables 1-4.

² $\pi r^2 h / 3$: actual measurements taken from size class A (h=6m, r=1.25m); values estimated for size class B (h=7.5m, r=1.7m), and for size class C (h=9m, r=1.9m)

³ # of trees * foliage volume/tree: actual # of trees for each size class

⁴ total m³ foliage for all size classes

APPENDIX II

DETAILS OF THE CHEMICAL RESIDUE STUDY

PESTICIDE DEPOSITS OVER FORESTS: AERIAL VS. MISTBLOWER APPLICATION OF SPRAYS

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ABSTRACT

Spray deposition patterns on simulated and live foliage of balsam fir and white birch were determined at different heights and at periphery and interior locations of the tree crown, following aerial and mistblower applications of formulations containing fenitrothion, over a boreal forest near Searchmont, Ontario. Droplet size spectra and deposits of AI were assessed at ground level using Kromekote card/glass plate units. Aerial application was made with a Cessna 188 aircraft fitted with Micronair AU3000 atomisers. For mistblower application, a Soloport 423 backpack mistblower fitted with an extension tube and a diffuser nozzle at the tip was used.

Deposit data on the ground samplers indicated significantly larger droplets and greater deposits in the aerial spray trial than in the mistblower treatment. However, foliar deposits at tree canopy level were only slightly higher in the former spray trial than in the latter, indicating that the two delivery systems can provide similar foliar deposits if the operational conditions were optimized in calibration trials.

Analysis of spray deposits on the simulated and live fir foliage showed definite gradients in deposit levels, decreasing from top to bottom crown, and from periphery to inner tree crown. In the birch tree crown, such gradients were not observed. Generally the simulated leaves acted as better collectors of spray droplets than the natural leaves. The overall mean deposit values, expressed in ng/cm^2 , showed a wide variation, although there was generally a good relationship between the deposits on the simulated and natural surfaces.

1. Introduction

The use of an aircraft for forestry spraying of pesticides has demonstrated to be the most competitive means of tree protection in Canada since the areas to be treated are large.¹ However, for spraying small young trees, air-carrier sprayers, such as the knapsack mistblowers, are particularly useful for projecting the droplets up into trees by means of a high-velocity air-stream (60 m.s.^{-1}). The air-stream velocity improves penetration and even-distribution of sprays into dense canopies and facilitates impaction of small droplets on the target with turbulence,² and minimizes fallout and ground contamination.^{3 4} However, data are sparse in the literature on the comparative aspects of canopy penetration, vertical and radial distribution of sprays in tree canopy, and foliar and ground deposition following aerial and mistblower applications onto small forest trees.

The use of simulated samplers for deposit collection provides many advantages. The pesticide chemical will not metabolize as fast on simulated samplers as in biological ones, so that a more accurate picture of

the active ingredient (AI) deposits can be obtained. Secondly, the extraction and column cleanup procedures for gas-liquid-chromatographic (GLC) determination of the AI deposits are much simpler because of the absence of interfering materials present in the biological samples. Therefore, a study of the relationship between the deposits on simulated and live foliar surfaces would provide information on the suitability of using such surfaces for deposit collection.

The present study was designed to examine if a mistblower application from ground level can provide foliar deposits similar to those obtained from an aircraft, and was a part of a larger project to investigate the impact of insecticide spraying on forest song birds (Milliken, personal communication). The design included investigation of spray deposition patterns on simulated and live foliage of balsam fir, *Abies balsamea* (L.) Mill., and white birch, *Betula papyrifera* (Marsh.), at different crown heights and at periphery and interior locations of the trees, following aerial and mistblower applications of a formulation containing fenitrothion, and to determine the ground deposits resulting from the two treatments. The objectives were to investigate (i) the differences in droplet size spectra, ground deposits and foliar concentrations between the aerial and mistblower applications, (ii) the relationship between deposits on simulated and live foliage, and (iii) the vertical and radial distributions in deposits on foliage of balsam fir and white birch trees.

2. Experimental

2.1 Materials

2.1.1 Aerial application study

The aerial application study was conducted in 1985. The spray formulation consisted of technical fenitrothion (Sumithion, Sumitomo Chemical Co., Osaka, Japan) 15% (v/v), mixed with Atlox 3409F (Atkemix, Brantford, Ont., Canada) 1.5%, Dowanol TPM (Dow Chemical, Sarnia, Ont., Canada) 1.5%, Rhodamine B (Allied Chemical, Morristown, New Jersey, USA) 1%, and water 81%.

2.1.2 Mistblower application study

The mistblower application study was conducted in 1986. The ingredients of the spray formulation used in this study were the same as those described in 2.1.1., but their percentage compositions were different: technical fenitrothion 4.5% (v/v), Atlox 3409F 1.5%, Dowanol TPM 1.5%, Rhodamine B 1% and water 91.5%.

2.2 Methods

2.2.1 Spray block descriptions

The spray block (B85, 49 ha) used for the aerial application study was selected in a boreal forest area about 10 km north of Searchmont (coordinates, N 46°52', W 84°00') in Township 24 R11, Algoma District, Ont., Canada. The block was dominated by cedar and alder as well as by young balsam fir and white birch trees. The mean canopy height of all tree species was around 8 m. An area (8 ha) was established approximately in the middle of the spray block (Fig. 1) for selecting sample trees and for placing artificial samplers to assess spray deposits.

The spray block (B86, 2.43 ha) used for the mistblower application study was located approximately 1 km north of the 1985 site. The topography of the block was very similar to the one used for the aerial application study. Nine spray lines, each 20 m wide, were established in the spray block (Fig. 2) for fenitrothion application.

2.2.2 Sampling trees

For the aerial application study, six trees, each of balsam fir and white birch [total height 7 ± 1 m; crown height 6 ± 0.5 m; crown diameter (base) 2.5 ± 0.5 m; and diameter at breast height 11 ± 3 cm; for both species], were selected randomly within the 8 ha sampling area (Fig. 1). For the mistblower application study, however, nine sampling trees in each of balsam fir and white birch, similar to those used in the 1985 study with respect to height and shape, were selected approximately in the middle of the spray block (Fig. 2). Three fir/birch pairs were located at 2 ± 0.1 m, three pairs at 10 ± 0.1 m and the last three pairs at 18 ± 0.1 m, away from the spray lines.

2.2.3 Simulated samplers

For simulating fir foliage, aluminum coil clusters (individual coils having a diameter similar to that of mature balsam fir needles) were used.⁵ These were placed on the fir tree crown using a pole pruner at 1, 3 and 5 m heights, starting from the crown tip. These heights represented the top, middle and bottom sampling sites (Table 1) of the tree crown. At each of the mid and bottom crown levels, one cluster was placed horizontally near the stem of each tree representing respectively, the mid-interior and bottom-interior sampling sites of the tree.

Aluminum branches containing 10 to 15 aluminum leaves, having the same dimensions as the natural birch leaves, were placed on the birch trees, at the same heights and locations as those on the fir trees.

2.2.4 Ground sampling units

The conventional Kromekote card/glass plate units⁶ were used for determining the ground deposit levels and droplet size spectra. For the aerial application study, 12 such units were placed in locations shown in Fig. 1, each on an aluminum stand 15 cm above the forest floor, at 1 h prior to spray application. For the mistblower application study, however, 30 such units were placed in locations shown in Fig. 2.

2.2.5 Spray application and meteorological conditions

For the 1985 study, a Cessna 188 aircraft equipped with four Micronair AU3000 atomizer units with blade angles set at 35°, applied the spray at a dosage rate of 280 g AI in 1.5 L/ha and at a emission rate of 18 L/min, flying at a speed of 160 km/h with a swath interval of 45 m. Spray was applied at a height of 15 m above the tree canopy and at right angles to the prevailing wind, on June 14/1985, between 0715 and 0800 h. The meteorological conditions that existed at the time of spraying were: wind speed 2 ± 0.5 km/h, temperature $15 \pm 1^\circ\text{C}$, relative humidity (RH) 80% and the cloud cover 0/10.

For the 1986 study, a Soloport 423 backpack mistblower (70 mL engine capacity) fitted with an extension tube and a diffuser nozzle (Solo Incorporated, P.O. Box 5030, 5100 Chestnut Ave., Newport News, Virginia, USA) was used to apply the spray on June 18/1986, between 1107 and 1156 h, at a dosage rate of 293 g AI in 5.2 L/ha. Prior to the actual study, the mistblower was calibrated using a simulant having the

same physical properties as those of the fenitrothion formulation used to determine the operational parameters required (details of calibration procedures are given elsewhere; Millikin, personal communication). The operator walked along each spray line at an even space (0.5 m/s), holding the nozzle vertically upwards and emitting the spray uniformly at 0.312 L/min. The meteorological conditions that prevailed during spray application were: wind speed 9.6 ± 1.0 km/h, temperature $21 \pm 1^\circ\text{C}$, RH 50% and the cloud cover 0/10.

2.2.6 Sampling and storing procedures

All samples, both natural and simulated, were collected at 1 h after spray application.

For investigating the vertical distribution of fenitrothion in the peripheral foliage, one branch 30 cm long, was clipped from the location adjacent to the simulated sampler, from each of the top, mid and bottom crown levels. For determining the radial distribution, sufficient branch segments were taken from the mid-interior and bottom-interior levels, adjacent to the positions of the simulated samplers. All samples were placed immediately in portable coolers and stored at 0°C .

The simulated aluminum branches on the fir and birch trees, and the glass plates of the ground sampling units were all collected and immediately transported to the nearby field laboratory (improvised), where the fenitrothion deposits were extracted at once from the samplers using ethyl acetate as the solvent. The extracts were placed in amber-colored bottles and stored in coolers at 0°C .

At the end of the field trials, the fir and birch foliage samples, and the extracts of the simulated samplers, were all transported to the

Sault Ste. Marie laboratory, where they were stored in freezer at -20°C until analysis by (GLC).

The Kromekote cards were collected, wrapped in aluminum foil and stored in dark in a desiccator.

2.2.7 Sample preparation, extraction, column cleanup and GLC analysis of deposits on natural and simulated foliage

In the aerial application study, samples of the natural and simulated birch foliage, collected from similar locations of the six trees, were divided into three sets for triplicate measurements, i.e., those from tree No. 1 were combined with those of No. 11 (Fig. 1), No. 4 with 10 and No. 5 with 7, to form three sets of composite samples. Similarly, the fir foliage samples from tree No. 2 were combined with those of No. 12, No. 3 with 9, and No. 6 with 8, to form three sets of composite samples.

In the mistblower application study, however, samples from the nine trees of each species were analysed individually to provide nine sets of deposit data.

Procedures used for extraction, column cleanup and GLC analysis of the live foliage were the same as those described by Sundaram and Sundaram⁷, except that neutral aluminum oxide (Merck--Activity Stage I, supplied by Canlab Chemicals, Toronto, Ont., Canada) was used for column cleanup instead of the Nuchar SN charcoal). The data were expressed in ng/g (mean $\pm$ SD) of fresh foliage (Table 1). The minimum detection limit of the measurement technique was 50 ng/g. The data was also converted into ng/cm² (mean $\pm$ SD) using the surface area and mass of a leaf, and the number of leaves per g fresh weight (Table 1).

Fenitrothion deposits on the simulated fir and birch foliage, which were extracted in the field laboratory, were analysed directly by GLC without any column cleanup procedures. The AI deposits were converted into ng/cm^2 (Table 1) using the surface area of the samplers.

2.2.8 Analysis of spray deposits on ground sampling units

2.2.8.1 Droplet analysis on Kromekote cards

Droplet stains on the Kromekote cards were analysed by the National Aeronautical Establishment (NAE) of the National Research Council of Canada (NRCC), Ottawa, using the Flying Spot Scanner.⁸ The data obtained from the 12 cards (Fig. 1) used in the aerial application study were pooled, the stain diameters were converted into the corresponding spherical droplet diameters by using a correction factor for droplet spreading,⁹ and the number and volume, median diameters ($D_{N.5}$ and $D_{V.5}$ respectively), maximum diameter (D_{max}) and droplet density (droplets per cm^2) were evaluated.¹⁰ The data were also used to compute the percentage frequency and volume distribution according to diameter classes and presented as histograms in Fig. 3. Similar calculations were carried out for the 30 Kromekote cards placed in the mistblower application study to obtain the droplet parameters and histograms (Fig. 3) for the 1986 study.

The minimum detection limit of the droplet sizing technique was 10 μm .

2.2.8.2 Deposit analysis on glass plates

The deposits on glass plates, which were extracted in the field laboratory, were analysed for fenitrothion by the GLC technique without

any column cleanup, and the data were expressed in g AI/ha and percent recovery of the applied fenitrothion (Fig. 3).

3. Results and discussion

3.1 Droplet size spectra and deposits on ground samplers--aerial vs. mistblower application

The D_{max} , $D_{N.5}$ and $D_{V.5}$ values, and the frequency and volume distribution histograms (Fig. 3) indicated unequivocally that spray droplets deposited on the ground samplers in the aerial application study were markedly larger than those observed in the mistblower study. Since flat samplers placed at ground level have been shown to collect predominantly the upper end of the droplet size spectrum emitted, it can be assumed that the mistblower had emitted smaller droplet sizes than the aircraft. On the other hand, both delivery systems could have emitted similar large droplet sizes at the release point; but under the high RH conditions (90%) observed in the aerial application study, the droplets probably underwent minimal evaporation in-flight, thus maintaining the same large sizes at the ground level as well. However, under the low RH conditions (50%) that existed in the mistblower application study, the released large droplets could have evaporated considerably in-flight, thus decreasing in sizes upon reaching the ground level. Both processes could have caused the observed differences in the droplet size spectra of the two spray clouds.

The large droplets found at ground level in the aerial application study, must have had sufficient energy to impact on the flat ground samplers, thus resulting in a higher droplet density on the Kromekote

cards, and greater deposition on the glass plates (Fig. 3) than those observed in the mistblower study.

3.2 Average fenitrothion deposits on canopy foliage--aerial vs. mistblower application

The data in Table 1 show that the average fenitrothion concentrations in canopy foliage (i.e., in both fir and birch foliage), expressed in ng/g or ng/cm², were slightly higher in the aerial spray trial than in the mistblower treatment, although no significant difference was noted between the data in the two applications (ANOVA P 0.05) due to the large standard deviations obtained. The higher aerial spray deposits were noticeable even with the simulated surfaces. This trend was due to the larger droplets present at the canopy level in the aerial spray trial, as compared to the smaller droplets present in the mistblower study. Large droplets [i.e., those with a $D_{v.5}$ of about 60 μ m (see Fig. 3)] are expected to impact on foliage more efficiently than small droplets (with a $D_{v.5}$ of about 30 μ m), resulting in higher foliar concentrations.

The comparable mean canopy deposits obtained in the aerial and mistblower applications, in spite of the markedly different drop sizes present, can be attributed to the wind speeds that prevailed during the two treatments. In the aerial spray trial, the wind speed was low (2 km/h), compared to the higher value (10 km/h) observed in the mistblower study. Higher wind speeds were known to increase the turbulence in the vicinity of canopy foliage, provide the required kinetic energy to the small droplets and enhance foliar impaction in forestry applications.¹¹

In the case of aerial application, the average deposits (in ng/cm^2) on live or simulated foliage were slightly higher on birch leaves than on fir needles, although there was no significant difference between the two surfaces. In the mistblower application, however, the average deposits were slightly lower (but not significantly lower) on birch leaves than on fir needles. The reason for this trend lies in the shape of the birch leaves, since flat surfaces are known¹² to collect lower number of the smaller droplets than the needle-shaped fir leaves.

3.3 Relationship between deposits on simulated and live surfaces

In both studies, the simulated surfaces received significantly higher AI deposits (ANOVA $P = 0.05$) than the natural surfaces. This trend was evident on both fir and birch leaves, and at all sampling locations of the canopy (Table 1). This observation is in agreement with that reported previously⁴ in aerial spray trial using mexacarbate. It appears that biological samples, irrespective of their surface characteristics, tend to receive lower deposits than metallic objects. The reason could be that a biological surface is a weaker conductor of electrical charges than a metal surface. As a result, the metal surface might have received a greater number of spray droplets than the biological samples. On the other hand, the chemical might have degraded partly during the first hour post-spray before the foliage samples were collected, a phenomenon which could not have occurred on the metallic samplers. These aspects, however, require further investigations.

3.4 Vertical distributions of deposits in the periphery of the tree crown

From the deposit levels listed in Table 1, it is evident that the top portion of the fir tree crown received the maximum deposits, in both aerial and mistblower application studies. This behavior was observed in both simulated and live fir foliage. This finding is in agreement with that reported by others, ⁵ 13-18 and is due to the filtration of spray droplets by the conifer canopy. However, such vertical gradients in deposits were not apparent in the birch tree crown, since no marked differences were noticeable in the mean deposits from top to bottom in either of the two studies. Such differences between the two tree species could be due to the distribution of foliage within the tree crown and also due to the different shapes of leaves of the two tree species. As a result, different micrometeorological factors could be associated with the two tree crowns, causing differences in droplet deposition patterns and canopy filtration of droplets.

3.5 Radial distribution of deposits in the tree crown

Similar to the vertical distribution of the chemical in the tree crown, the radial distribution also showed considerable differences in the deposits between the mid-crown periphery and mid-interior of the tree in both aerial and mistblower applications. Such a trend also existed in the bottom periphery and bottom-interior levels (Table 1). However, none of these radial gradients were noticeable in the birch tree crown in either of the two studies, since the deposit values were quite similar in all radial locations. The reason for these differences could be the same as those mentioned in Section 3.4.

3.6 The usefulness of aluminum surfaces for deposit collection in forestry spraying

In spite of the marked differences observed in the deposits between the simulated and live foliar surfaces, there was a general trend for proportional variation in the deposits at similar sampling locations; i.e., when the deposit was high on an aluminum sampler in a location, there was a correspondingly high deposit on the biological sample collected from the same location. This implies that the aluminum samplers can provide a relative picture of the distribution of spray deposits in different components of the forest ecosystem, although they cannot provide a picture of the actual residues present in the biological samples.

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Fig. 1. Locations of the sampling trees and Kromekote[®] card/glass plate units in the 8 ha sampling area (aerial application study).

Fig. 2. Locations of the sampling trees and Kromekote card/glass plate units in the 2.43 ha spray block (mistblower application study).

Fig. 3. Frequency and volume distribution percentages according to size category. The deposit levels on ground sampling units were: droplets/cm² 14, AI deposit 73 g/ha, and percent recovery 26 for aerial application; droplets per cm² 5, AI deposit 1.7 g/ha, and percent recovery 0.6 for mistblower application.