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INTRODUCTION

The balsam gall midge, *Paradiplosis tumifex* Gagné is found throughout Maine and over most of the natural range of balsam fir, *Abies balsamea* (L.) Mill., and Fraser fir, *A. fraseri* (Pursh) Poir., in North America (Giese and Benjamin 1959). This midge is a severe pest when Christmas tree plantations are heavily infested. Defoliation occurs because needles drop prematurely from late September through November of the year of infestation (Osgood and Gagné 1978) (Figure 1).

The midge overwinters in the litter beneath previously infested trees as third instar larvae. Pupation occurs in the spring and adults emerge in mid-May in Maine. Eggs are deposited on newly opening buds (Figure 2) and hatch in 2-3 days. Galls begin to form soon after eclosion with needle tissue growing around the first instar larvae. Midges reach the third instar in September and vacate galls in late September and early October to drop to the litter.

Population levels of balsam gall midge are naturally regulated by several mortality factors. *Dasineura balsamicola* (Lintner) is an "inquiline" of the balsam gall midge and is an important mortality factor (Osgood and Gagné 1978). Osgood and Dimond (1970) found nine species of Hymenoptera parasitic on populations of *D. balsamicola*. MacGown and Osgood (1972) found a total of seventeen species of chalcidoid and proctotrupoid Hymenop-

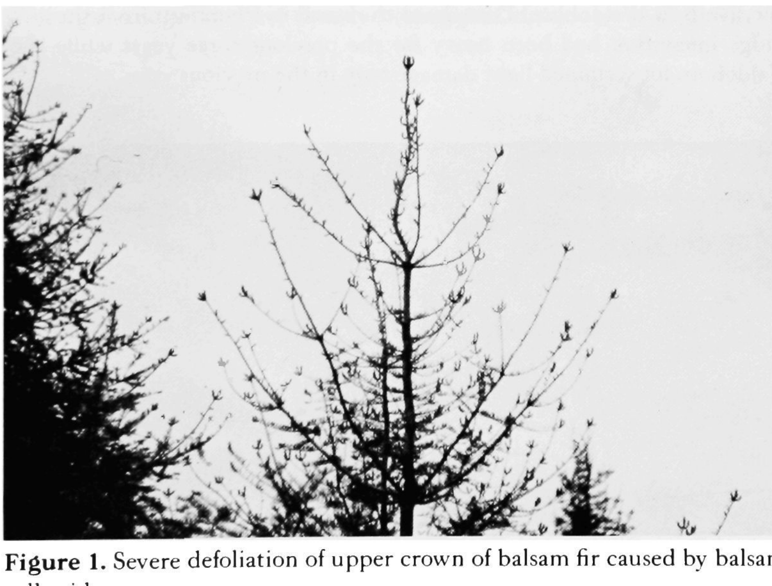

Figure 1. Severe defoliation of upper crown of balsam fir caused by balsam gall midge.

tera associated with *D. balsamicola*. Both studies of parasites of *D. balsamicola* were carried out on mixed populations of this species and *P. tumifex*. Connor and Osgood (1979) found six species and/or genera of parasites attacking *P. tumifex*, the gallmaker. Struble and Osgood (1976) examined damaged galls and found up to 39% predation. Avian predation was suspected, but not confirmed.

Osgood (1977) obtained excellent control of balsam gall midge using diazinon applied at 0.84 kg AI/ha, but Christmas tree producers recently expressed concern over being limited to a single insecticide. In addition, the "window" for control was short and very restrictive for growers. This study was undertaken to test new insecticides for control of the balsam gall midge and to determine effectiveness of later insecticide application in order to expand the effective period for control.

MATERIALS AND METHODS

Spray trials were conducted in Plymouth, Maine in Penobscot County on 28 May 1984 and on 26 May 1985 and in Waldoboro, Maine in Lincoln County on 6 June 1987. Both stands were comprised of thinned natural regeneration of balsam fir ranging in height from 1.5 to 5 m. The trees had become established in an old field (Figure 3) in Plymouth and in cut over woodlands in Waldoboro. Damage to the stand in Plymouth from the gall midge infestation had been heavy for the previous three years while the Waldoboro lot sustained light damage only in the previous year.

Figure 2. Adult balsam gall midge ovipositing on developing bud in May.

Four insecticides were selected for efficacy tests in 1984; diazinon, chlorpyrifos, permethrin and fenvalerate. Formulations and application rates are shown in Table 1. Diazinon was used as a standard applied at 0.84 kg AI/ha and, in addition, reduced application rates of diazinon were tested. Chlorpyrifos, permethrin and fenvalerate had proven efficacious against balsam twig aphid and were tested against balsam gall midge since it would be useful if the same chemical could be used for both pests. In 1985, reduced application rates of diazinon and chlorpyrifos were tested. Technical difficulties in the 1985 tests required additional testing of the reduced rates of diazinon and chlorpyrifos in 1987.

A completely random design was utilized with six 0.1 ha blocks and two 0.05 ha blocks in 1984, six 0.1 ha blocks in 1985 and four 0.05 ha blocks in 1987. Natural buffers of at least 15 m of open field were maintained between blocks in Plymouth. A logging road and natural openings were used as buffers in Waldoboro. Samples of 20 current year shoots from the upper 1/3 of the crown were randomly selected within each block as a sampling unit. No prespray sample was taken as the first instar larvae are very difficult to count particularly when buds are not yet fully elongated and flattened.

Insecticides should be applied after oviposition is completed, and most of the eggs have hatched. It is also essential to have the buds of the host tree elongated and flared sufficiently to allow penetration of the spray droplets to the base of the needles. To provide data on efficacy of chemicals to control balsam gall midge that have already formed galls, diazinon was applied on 5

Figure 3. Plymouth plantation, a naturally seeded stand with great variability in size and spacing in and between trees.

Table 1.
Formulations and application rates of insecticides tested for control of balsam gall midge.

Formulation	Common Name	Year of Test	kg AI/ha
Ambush 2E	permethrin	1984	0.22
Ambush 2E	permethrin	1984	0.11
Diazinon AG500	diazinon	1984, 1985, 1987	0.84
Diazinon AG500	diazinon	1984	0.56
Diazinon AG500	diazinon	1985	0.37
Diazinon AG500	diazinon	1985, 1987	0.28
Lorsban 50WP	chlorpyrifos	1984	0.56
Lorsban 50WP	chlorpyrifos	1985	0.37
Lorsban 50WP	chlorpyrifos	1985, 1987	0.28
Pydrin 2.4EC	fenvalerate	1984	0.11

June and 10 June 1984, 8 and 13 days, respectively, after gall formation began.

Insecticides were applied with a Stihl SG17 backpack mistblower at a rate of 46.8 l/ha of finished spray (insecticide plus water). The aperture was set at No. 1 to provide this rate. Trees to be sampled in each block were marked with plastic flagging to insure spray coverage. This was necessary since trees were not in uniform rows which made it difficult to walk through portions of the blocks.

On 26 May 1984, the temperature was approximately 8°C with calm wind and a high overcast. Spraying began at 8:45 a.m. and was completed at 10:30 a.m. All applications were dry on the foliage by 10:45 a.m., light rain began at 11:30 a.m. and continued for four days. On 5 and 10 June the temperature was 21°C and no precipitation fell within two days. In 1985 the temperature was approximately 21°C, winds were light and variable and the sky was clear. Application was delayed until the foliage dried at 12:15 p.m. Application was completed by 2:00 p.m. and no rain fell within the following 24 hour period. In 1987 the temperature was approximately 20°C, winds were light from the west and the sky was clear. Foliage was dry at 11:00 a.m. and insecticide application began at 11:15 a.m.

Samples for insecticide efficacy were collected on 16 and 17 July in 1984 and 1985 and on 22 July in 1987. Two current year shoots from each of ten trees were collected from the upper third of the crowns for each treatment. At the laboratory, developed and undeveloped galls (Figure 4) were counted using a dissecting microscope and the numbers recorded. Developed galls contained the midge larvae. Undeveloped galls indicated a larva was originally present, but had been killed, thereby arresting the gall development

Figure 4. Undeveloped (top) and developed (bottom) galls on balsam fir caused by larvae of the balsam gall midge.

in the early stages. It was necessary to open many galls with very fine tipped forceps to determine if living or dead larvae were present.

Since population counts did not conform to assumptions of normality required for parametric statistical tests, it was necessary to use nonparametric analysis. Data on developed galls were subjected to a Kruskal-Wallis test. Individual differences between treatments were distinguished utilizing the Wilcoxon test.

RESULTS AND DISCUSSION

The total number of galls per shoot (developed plus undeveloped) gives an estimate of the number of midge larvae present prior to treatment. Results of all trials found no significant differences between blocks prior to treatment within a given year. A Kruskal-Wallis test did show a significant difference between means of ranked data when only data for developed galls (equals live larvae) were used. This indicates a treatment effect.

Results for 1984 treatments are shown in Table 2. Using Wilcoxon scores, data are grouped into three categories with diazinon and chlorpyrifos at all rates and timing being very effective. The control block maintained a high number of live midge larvae throughout the test. The pyrethroids, fenvalerate and permethrin, were intermediate in ability to control midge populations. Field observations a few days after treatment found many of the exposed larvae dead in the pyrethroid blocks, but those that had begun to develop galls prior to treatment were alive.

The midge oviposition period in 1984 extended from 17 May to 27 May. Eggs hatch in 2-3 days. Adults, eggs and first instar larvae (some enclosed in galls) may then be observed at one time. Therefore, chemicals such as diazinon and chlorpyrifos that control the midge even after they are enclosed in galls, provide excellent control. Pyrethroids, which must contact the larvae, are unsatisfactory.

Table 2.
The mean numbers of developed galls per shoot on balsam fir treated in insecticide trials for control of gall midge in 1984.

Treatment	kg AI/ha	Date Applied	Mean No. Developed Galls per shoot*
diazinon	0.84	28 May	0.45 a
diazinon	0.56	28 May	1.5 a
diazinon	0.84	5 June	0.7 a
diazinon	0.56	10 June	4.25 a
chlorpyrifos	0.56	28 May	0.0 a
permethrin	0.22	28 May	36.9 b
permethrin	0.11	28 May	25.8 b
fenvalerate	0.11	28 May	34.2 b
control	—	—	61.9 c

*Numbers followed by the same letter are not significantly different ($\alpha = 0.05$ Wilcoxon scores).

Diazinon applied five to ten days after eclosion provided excellent control even though many of the galls were completely formed. This lengthens the spray "window" considerably. Prior to this study, application was made immediately after eclosion was completed. Data (Table 2) show that control is effective at least ten days after egg eclosion. Field observation of galled needles showed that needles remained on the trees throughout the year if larvae are killed even after the galls have formed.

Tests to control balsam gall midge were continued in 1985 to determine if lower application rates of diazinon and chlorpyrifos were efficacious. Results of these tests are presented in Table 3. Control was not acceptable in any of the test blocks. To achieve good control, it is necessary to apply insecticides following eclosion and after new shoots have elongated and flattened out to provide a good spray target. In 1985 the development of the gall midge was more advanced than its host and sprays were applied too early. The insect development was correct, but spraying proved to be too early because incomplete foliage expansion caused poor spray coverage. Control was very erratic as the phenology varies greatly in balsam fir plantations, and the early bud breaking trees exhibited good control while trees with delayed development showed little or no control.

Table 3.
The mean numbers of developed galls per shoot on balsam fir treated in insecticide trials for control of balsam gall midge in 1985.

Treatment	kg AI/ha	Mean Number of Developed Galls per Shoot*
diazinon	0.84	27.8 b
diazinon	0.37	8.5 b
diazinon	0.28	3.2 a
chlorpyrifos	0.37	2.6 a
chlorpyrifos	0.28	11.3 b
control	—	17.3 b

*Numbers followed by the same letter are not significantly different ($\alpha = 0.05$ Wilcoxon scores).

Testing was done in 1987 to again assess the efficacy of 0.28 kg AI/ha rates of diazinon and chlorpyrifos. The timing of application was delayed until the fir foliage was elongated and well flared out. Gall formation had begun on some of the earliest developing tips. Results of the 1987 tests are presented in Table 4. Control was excellent in all treated blocks.

Continued work is necessary to develop a predictive survey of spring population levels. This will reduce the amount of insecticides applied as well as reducing the number of "preventative" applications commonly used.

Table 4.
The mean numbers of developed galls per shoot on balsam fir treated in insecticide trials for control of balsam gall midge in 1987.

Treatment	kg AI/ha	Mean Number of Developed Galls per Shoot*
diazinon	0.84	0.02 a
diazinon	0.28	0.84 a
chlorpyrifos	0.28	0.15 a
control	—	33.95 b

*Numbers followed by the same letter are not significantly different ($\alpha = 0.05$ Wilcoxon scores)

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