ISSN 0734-9556

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Technical Bulletin 151

August 1992

MAINE AGRICULTURAL EXPERIMENT STATION
Maine

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ACKNOWLEDGMENTS

The authors wish to thank Dr. John Dimond, David Struble, and Dr. Rick West for critical review of the manuscript, and the Maine Forest Service and McIntire-Stennis appropriations for funding this project.

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FIGURES

INTRODUCTION

The gall on balsam fir needles has been known since Lintner (1888) implicated a gall midge, *Dasineura balsamicola* (Lintner), as the gallmaker. Giese and Benjamin (1959) also implicated *D. balsamicola* as the gallmaker. In the Maritime Provinces of Canada, Smith and Forbes (1962) reared two species of gall midges, *D. balsamicola* and *Paradiplosis* sp., from balsam fir galls, but did not determine the relationship between the two species. MacGown[1] (1974) distinguished two types of larvae and the incidence of each in needle galls of balsam fir in Maine. Osgood and Gagné (1978) determined that the actual gallmaker was a new species of *Paradiplosis*, *P. tumifex* Gagné, and that *D. balsamicola* was its "inquiline" The term inquiline is used here in the broad sense to identify the phytophagous gall inhabitant, *D. balsamicola*, that is incapable of initiating the gall in which it feeds.

The balsam gall midge, *P. tumifex*, is probably found throughout 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, periodically, is a severe pest of balsam fir Christmas trees. Defoliation occurs because galled needles abscise prematurely from late September through November and medium to heavily infested trees are unsuitable for Christmas trees or wreath material (Fig. 1). Probably more than 300,000 balsam firs are cut annually in Maine and seven million in New England and the Canadian Maritime Provinces for Christmas trees.

This technical bulletin summarizes all previous published research on the balsam gall midge. Also included are new data on the effect of late bud burst on midge oviposition and the degree of population regulation of the gallmaker by its inquiline.

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[1] Unpublished data on file in the Department of Entomology at the University of Maine.

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

TAXONOMY

The taxonomy and relationships of the gallmaker and its inquiline as clarified by Osgood and Gagné (1978) are

The inquiline, *Dasineura balsamicola* (Lintner)

Cecidomyia balsamicola Lintner 1888:60 (larva only, gall incorrectly associated) Types probably lost.
Dasyneura (sic) *balsamicola*: Giese and Benjamin 1959: 193 (adult only, larva misidentified).

The gallmaker, *Paradiplosis tumifex* Gagné
Cecidomyia balsamicola Lintner 1888:60 (gall only, larva incorrectly associated).
Dasyneura balsamicola: Giese and Benjamin 1959:193 (larva only, adult incorrectly associated).

DESCRIPTION OF LARVAE AND ADULTS

Complete descriptions of the larvae and adults of *P. tumifex* and *D. balsamicola* are given in Osgood and Gagné (1978). The following is taken almost exclusively from that paper. Much of the descriptive information was selected so that *P. tumifex* could readily be distinguished from its inquiline *D. balsamicola*. The following differences in the two species can be seen in Figs. 2–15.

P. tumifex

Larva—Head capsule width: instar I, 0.05 mm; II, 0.06 mm; III, 0.10 mm. Body length: instar I, 0.35–0.67 mm; II, 0.94–1.12 mm; III, 1.28–2.75 mm. Integument smooth except for rows of minute spinules on various parts of the body particularly on anteroventral areas of segments. Sternal spatula present in instar II, the latter part of June in central Maine, but shaft shorter than spatula of instar III.

Adult—Male and female flagellomeres as in Figs. 10 and 11. Wings with vein R_5 joining C at the wing apex (Fig. 14).

D. balsamicola

Larva—Integument is lumpy with rows of segmental spines (Fig. 9). Sternal spatula not present until the III instar, the latter part of September in central Maine.

Adult—Antennal flagellomeres of male uninodal and of female sessile (Fig. 12 and 13). Wings with R_5 vein joining C based of the wing apex (Fig. 15).

Other distinguishing larval characteristics that are helpful for larval identification when dissecting galls include the following. First instars of *D. balsamicola* have spines easily visible at 100x, but barely visible at 30x; these are absent in *P. tumifex*. Throughout the larval development periods of the two species, the following color differences can be noted:

	7/8/75	7/28/75	9/8/75
P. tumifex	white	white	yellow-orange
D. balsamicola	yellow	orange	orange

When mature, *P. tumifex* larvae are uniformly light orange, and *D. balsamicola* larvae are darker orange with still darker orange blotches. *D. balsamicola* larvae are more tapered anteriorly and much more active.

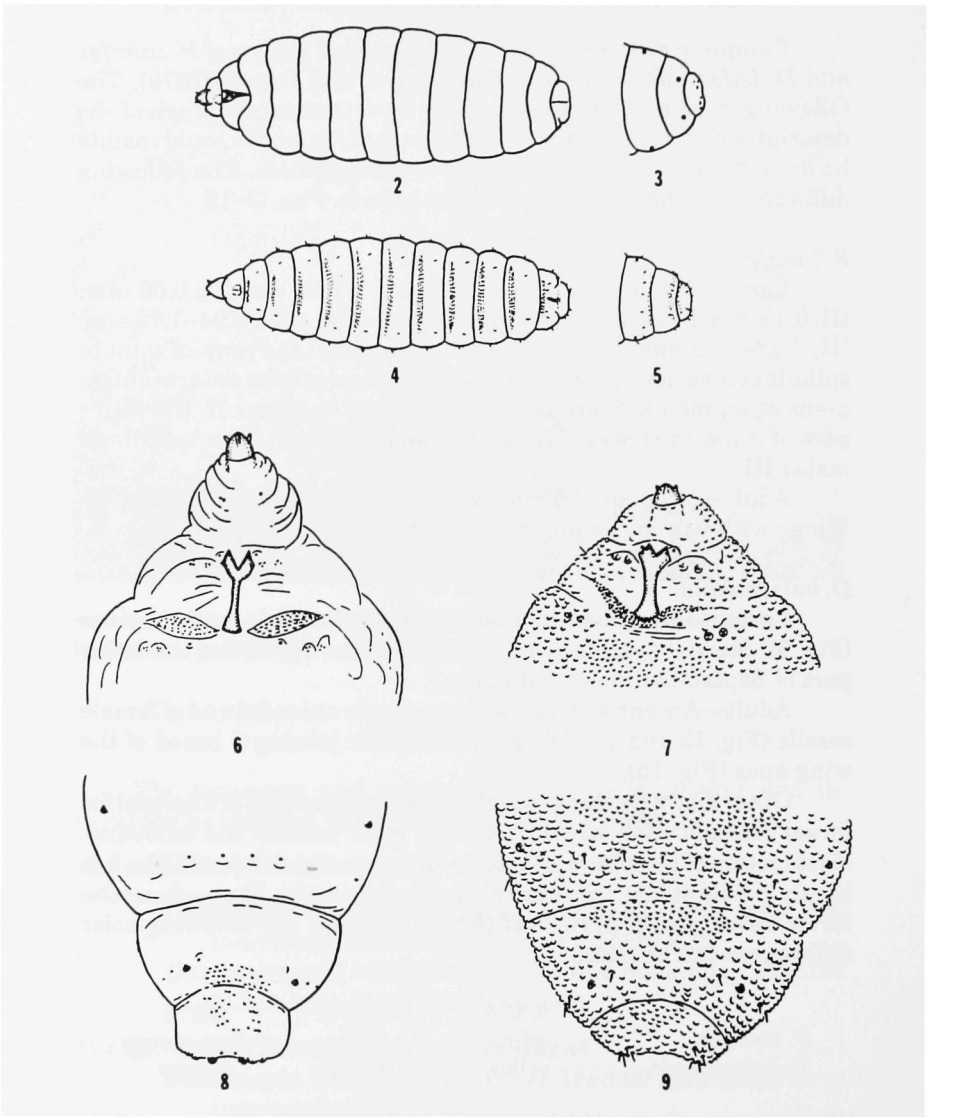

Fig. 2–9.–2–5. Second instars; entire, ventral; posterior segments, dorsal: 2–3, *Paradiplosis tumifex*; 4–5, *Dasineura balsamicola*; 6–9, 3rd instars, anterior segments, ventral; posterior segments, dorsal: 6, 8, *P. tumifex*; 7, 9, *D. balsamicola*. (Courtesy of R. J. Gagné, Sys. Ent. Lab. USDA.)

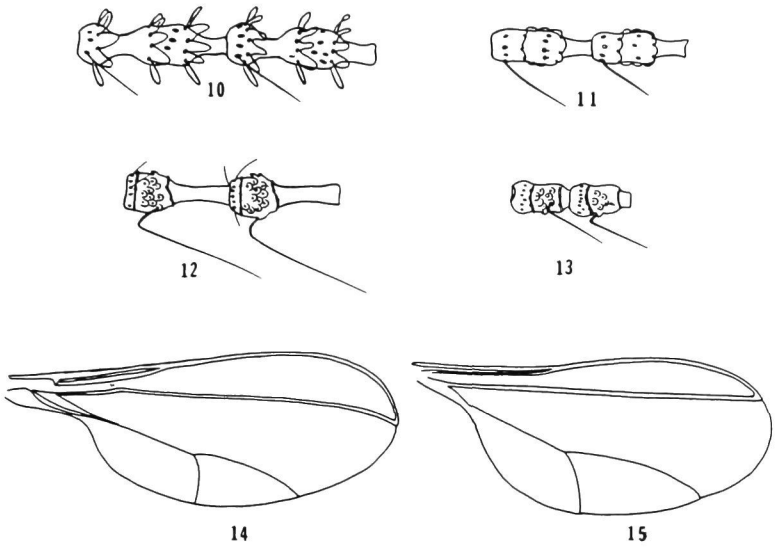

Fig. 10–15.–10–13. Antennal flagellomeres III–IV; 10, 12, male; 11, 13, females: 10–11, *Paradiplosis tumifex;* 12, 13, *Dasineura balsamicola;* 14–15, wings: 14, *P. tumifex;* 15 *D. balsamicola.* (Courtesy of R. J. Gagné, Sys. Ent. Lab. USDA.)

LIFE HISTORY AND BIOLOGY

Osgood and Gagné (1978) described the life history and biology of the two midge species in Maine. Figure 16 shows the generalized life cycle of both species. The adult female activity period of the two is approximately the same. Females oviposit in newly opening buds or under loosened bud scales of balsam fir; *P. tumifex* females oviposit shortly before those of *D. balsamicola*. Adult female activity period is approximately two weeks.

Midges are not strong fliers, and females have been observed by the authors to rest on the litter and grass at the base of host trees during wind gusts and to swarm from this location through the branches to terminal areas of the tree to oviposit when the wind subsides. They are easily observed ovipositing (Fig. 17) on bright days particularly in the late afternoon when breezes are light.

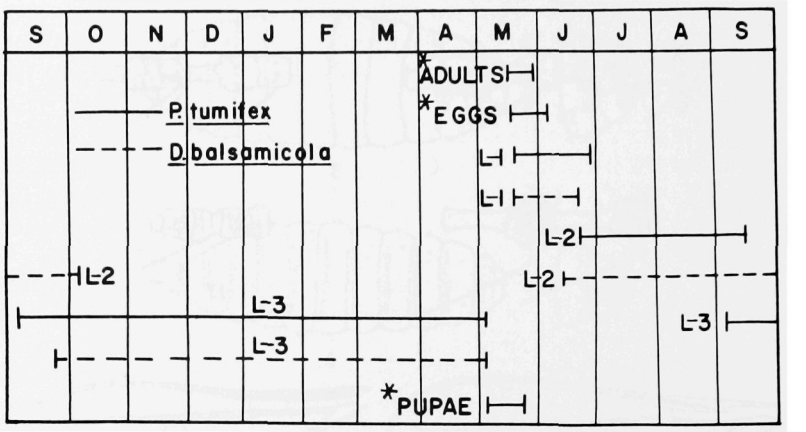

Fig. 16. Life history of *P. tumifex* and *D. balsamicola* from field observations and laboratory rearings. *Life history of eggs, pupae, and adults ca. the same for both species.

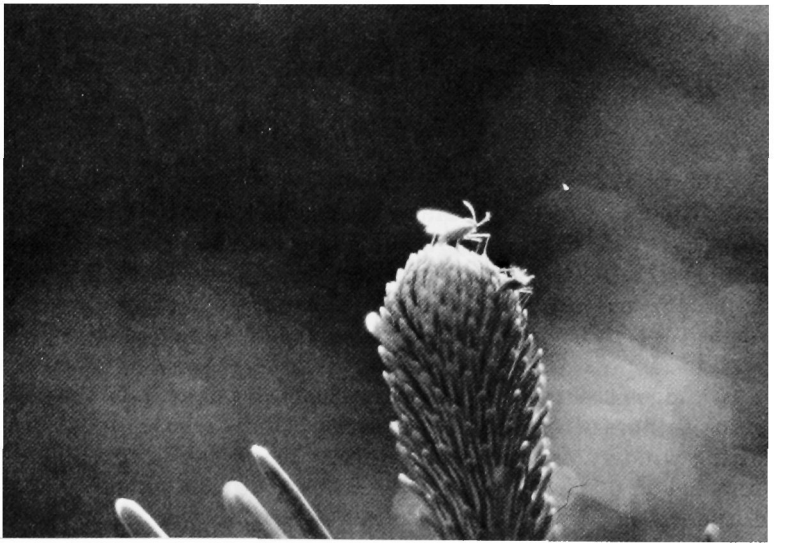

Fig. 17. Adult balsam gall midge ovipositing on developing bud in May.

Akar and Osgood (1987a) developed an emergence trap and collecting apparatus to capture midges and parasites as they emerged from the soil. In 1985 and 1986 adult *P. tumifex* were collected from May 13–23 and May 13–19 respectively (Akar 1987). There was no difference in the emergence dates of males and females. The male:female ratios of 274 adults collected in 1985 was 1:3.64, and for 311 collected in 1986 it was 1:2.65; pooled 1:3.1. The population of *D. balsamicola* was low in the area studied. *D. balsamicola* emerged from May 15–21 in 1985 and May 13–17 in 1986. The pooled sex ratio of 11 adults in 1985 and 6 in 1986 was 1:1.83.

Akar (1987) determined the number of eggs/female by dissection. Twenty-five *P. tumifex* females averaged 120 eggs. Eggs were fully developed and uniform in size at time of adult emergence. Twelve *D. balsamicola* females averaged 92 eggs, but *D. balsamicola* eggs were in various stages of development, and they may have the capacity to produce eggs after emergence.

Eggs hatch in 2–3 days. First instar larvae move to and usually settle on the proximal adaxial surface of developing needles. Needle cells near the larvae proliferate, and the larva appears to sink into the needle. Larvae are enclosed by the needle gall within the first week of feeding, with the exception of the ostiolar opening which is always present (West and Shorthouse 1982).

Akar and Osgood (1987b) determined how *D. balsamicola* comes to inhabit the gall. When galls were in the incipient stage, 1st instar *D. balsamicola* were found with their anterior in contact with a 1st instar *P. tumifex* larva. In this position, *D. balsamicola* larvae were less active than those not in contact with a *P. tumifex* larva. They were observed in contact with *P. tumifex* prior to visible gall formation, indicating that they are attracted to *P. tumifex* larvae and not to a surface characteristic of the needle such as an incipient gall. After hatching, *D. balsamicola* crawls near to a *P. tumifex* larva at the time of gall initiation and is enveloped in gall tissue along with the gall former. Thus, larvae of *D. balsamicola* actively seek *P. tumifex* larvae, but the entry of *D. balsamicola* larvae into the gall initiated by *P. tumifex* is passive. As many as six *D. balsamicola* larvae were observed surrounding a single *P. tumifex* larva in an incipient gall.

First instars of both species were found by May 19 in some areas in Maine, and the duration of this stage is longer in *P. tumifex*. Head capsule widths for both species range between 0.045–0.048 mm in the 1st instar, 0.058–0.062 in the 2nd, and 0.073–0.080 in the 3rd (Osgood and Gagné 1978). According to these head capsule measurements, all *D. balsamicola* were 2nd instars by June 20 and

P. tumifex by July 8. Larvae of *D. balsamicola* are in the 2nd instar considerably longer than those of *P. tumifex*. *P. tumifex* were all 3rd instars by September 23 in Maine, while all *D. balsamicola* did not reach that stage until October 6.

During dissection of mature galls Akar (1987) noted that 3rd instar *P tumifex* jump, often a distance of 5 cm or more. This jumping may be adaptive for escaping predators or for finding a more hospitable area to enter the litter. Tokuhisa et al. (1979) considered the jumping behavior of the Japanese cedar gall midge, *Contarinia inouyei* Mani, to be adaptive for their emergence from the gall and movement on the ground.

Both species overwinter as 3rd instars in the litter, but the date they enter the litter varies considerably between the two species. *P. tumifex* reaches the 3rd instar ca. two weeks before *D. balsamicola* (Fig. 16); it also leaves the gall through the ostiolar opening before *D. balsamicola*. Osgood and Gagné (1978) found that approximately half of the *P. tumifex* larvae had vacated the galls by September 26, 1975, before any *D. balsamicola* had dropped. Between September 26 and October 8 many galled needles dropped but needles containing *D. balsamicola* larvae persisted longer on the trees than those with only *P. tumifex*. The time of drop of *D. balsamicola* larvae was not determined in 1975.

Smith and Forbes (1962) determined that larval drop (probably *P. tumifex*) from galls at Fredericton, N.B., was from mid-September to mid-October, and that drop was generally greater on wet days or immediately after rainfall than on dry days. In the laboratory they found that larval drop was stimulated by soaking infested foliage with water.

In northeastern Vermont, Bergdahl and Mazzola (1985) determined that *P. tumifex* larvae began to leave the galls about September 13 and all had left by October 18, 1983. *D. balsamicola* larvae in their studies began to leave the galls in mid-October and all had left by December 8, 1983.

That the time of larval drop of *D. balsamicola* depends on the weather is shown by the following data. Gall samples were taken at weekly intervals in Stetson, Maine, in 1976 to accurately determine the dropping period for *D. balsamicola*. On the morning of November 27, 40 of 50 galls collected contained larvae of *D. balsamicola*. On November 29 only 2 of 50 galls collected from the same trees contained larvae of *D. balsamicola* (Osgood and Gagné 1978). November 27 and 28 were favorable for larval midge activity. Maximum air temperatures recorded at the nearby Bangor FAA weather station were 11°C on November 27 and 10°C on November

28, the highest recorded for the month. Precipitation recorded by the same station was 0.05 cm on November 27 and 0.64 cm on November 28. The senior author has often soaked infested foliage with a fine water mist spray in the lab to stimulate drop of both midge species for use in laboratory experiments.

D. balsamicola pupated in cocoons but *P. tumifex* did not (Osgood and Gagné 1978).

INTERRELATIONSHIP OF THE TWO SPECIES

Osgood and Gagné (1978) first determined the inter-relationship of the two midge species. When a single larva is found in the needle gall of balsam fir, it is always *P. tumifex*; when two or more larvae are found, one *P. tumifex* larva and one or more *D. balsamicola* larvae are present. *D. balsamicola* larvae are never found in galls without larvae of *P. tumifex*. Thus, it is *P. tumifex* that initiates gall formation.

As previously mentioned more than one *D. balsamicola* larvae may be present in a single gall. Two to three is common, and as would be expected, this occurs more frequently in older infestations where populations of *D. balsamicola* are high. All *D. balsamicola* larvae mature when there is more than one per gall, but *P. tumifex* larvae do not develop beyond the early 2nd instar when accompanied by larvae of *D. balsamicola*. Shorthouse and West (1986) suggest that *P. tumifex* with its thin integument is killed through abrasion by the spines of *D. balsamicola*.

Larvae of *P. tumifex* are larger than *D. balsamicola* larvae if they are the only gall occupant. The effect of *D. balsamicola* larvae on *P. tumifex* is evident as early as the first week of July, when most larvae of *P. tumifex* found in galls with *D. balsamicola* are smaller than those that are the sole gall occupant (Osgood and Gagné 1978). By the first part of August, all *P. tumifex* larvae found with *D. balsamicola* are smaller than normal. Mortality of *P. tumifex* begins in mid-August and from mid-August to mid-September living *P. tumifex* larvae are considerably smaller, darker, and less active than normal *P. tumifex* larvae. All *P. tumifex* larvae in galls with *D. balsamicola* were dead by October 6 (Osgood and Gagné 1978). Bergdahl and Mazzola (1985) found low levels of *P. tumifex* mortality as early as July 14 and 100% mortality by September 20.

Mortality of *P. tumifex* caused by *D. balsamicola* varies greatly with stand location and from year to year. Shorthouse and West (1986) reported 38%–50% mortality in three different years in Ontario. Osgood and Gagné (1978) reported mortality as low as 2% in light gall midge infestations and 48% in heavier infestations. *D.*

balsamicola was present in all areas examined in Maine. Population levels of the inquiline *D. balsamicola* appeared to be responding to the density of the gall maker.

Much additional data relative to this last point has been gathered in five Maine locations over the past 17 years. Mortality to *P. tumifex* caused by *D. balsamicola* was 80% or more in several instances, with a high of 88%. These data are shown graphically and discussed in detail in the following section.

Population Dynamics

Mortality of *P. tumifex* caused by *D. balsamicola* has been studied in five east central Maine locations; Edinburgh, Monroe, Old Town (2), and Stetson from 1975–1991. One of the Old Town sites was thinned and harvested seven years after the study's initiation. In each location the percentage of infestation of *P tumifex* and the percentage of occurrence of *D. balsamicola* were estimated from a nested sampling design. Ten to fifty current-year's twigs were randomly selected from the top two branch whorls, 1–2 from each of 10–25 trees within a site. Needle galls were counted, and a percentage of infestation of *P. tumifex* was calculated. A percentage of occurrence of *D. balsamicola* was estimated from dissection of 100–250 mature galls per site. Population sampling and dissection were conducted in July when both species were in the 2nd instar. The two species are most easily distinguished at this time on the basis of color and other characteristics mentioned earlier.

Time series analysis was conducted using the "SERIES" module in SYSTAT™ (Wilkinson 1989). Only 4 of the 5 sites were used in the time series analysis, since the thinned and harvested Old Town site (referred to here as site #1) had too few data points for modeling. Model estimation and diagnosis was performed using the methodology of Box and Jenkins (1976) and Wei (1990). The principal of parsimony (selecting the simplest model structure that still explains the dynamics) was adhered to in the model selection process (Box and Jenkins 1976). In addition, model selection was based upon analysis of the residuals (autocorrelation analysis). Forecast predictions of gall midge populations (expressed as percentage occurrence) were made for the last three years in which sample data were collected and then for the years 1991 or 1992–1995. Autocorrelation analysis was used to estimate periodicity of the gall midges and cross-correlation analysis was used to test for association and synchrony between *P. tumifex* and its inquiline.

Figure 18 illustrates the population dynamics of the gall midge species at the five sites in Maine. Comparing the *P tumifex* population fluctuations between sites, it appears that a degree of temporal synchrony exists between some of the sites, even though the sites are separated in geographical location. Correlation analysis of *P. tumifex* percentage infestation (excluding site #1) at lag=0 (i.e., time [t] correlated with time [t] and time [t + 1] with time [t + 1], etc.) supports this conclusion (Table 1). This is surprising since the tree stand age as well as the weather at these sites varied. It is not known if dispersal or migration play a significant role in synchronizing these populations or whether highly mobile density-dependent mortality factors such as disease or parasites contribute to this phenomenon. A similar situation exists with *D. balsamicola* (Table 2).

Since both of these species show a similar temporal synchrony over geographical locale, one might assume that the two gall midge populations covary with one another (density dependence of the gall maker with its inquiline). Cross-correlation analysis suggests that this might be the case. Significant correlations only occurred between the two species at a lag=1 (for sites: Stetson ($r=+0.68 \pm 0.51$); Monroe ($r=+0.81 \pm 0.72$); and Edinburgh ($r=0.60 \pm 0.54$)), meaning that a delayed density-dependent relationship of one year results between the two midges, typical of the classical host-parasitoid population interaction. The two midge species population dynamics were modeled separately, although a cross-correlation transfer function model (Wei 1990) would seem appropriate (and might yield better forecasts) for modeling the inquiline since *P. tumifex* appears to serve as a leading indicator of *D. balsamicola* population fluctuations. Third order density-dependent models (AR3: stationary autoregressive models) were the best behaved models of the ARIMA type models tested. For both species the model was of the form:

$$N_{(1+1)} = b_1N(t) + b1_2N_{(t-1)} + b_3N_{(t-2)} + a_t, \text{ where } a_t = N_{(t)} - N_{t-1)}(1).$$

We feel that the need for a third order density-dependent model is in part due to the limited time series available for each site. Similar type population data has been adequately modeled with second order density-dependent models (spruce budworm, Royama 1984) and even first order density-dependent models (blowfly, Brillinger et al. 1980). Unfortunately, a single parameterized model did not adequately describe all populations for a given midge species. Therefore, specific models were used for each site to forecast

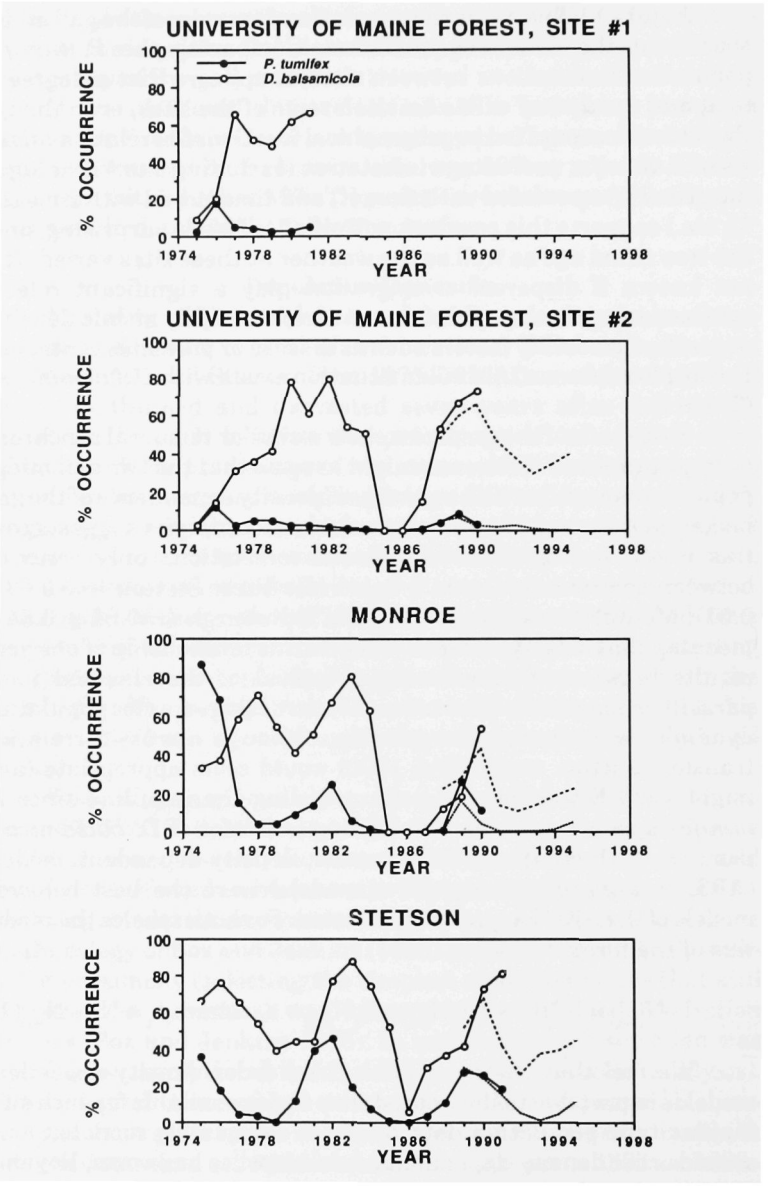

Fig. 18. Population dynamics of *P. tumifex* and *D. balsamicola* at five sites in east central Maine. Dashed lines are time-series predictions for *D. balsamicola* and dotted lines are predictions for *P. tumifex*.

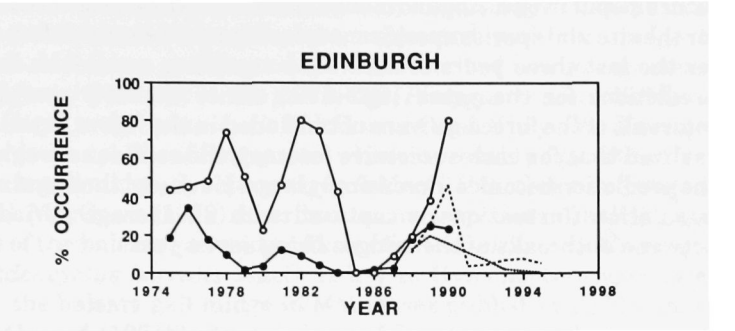

Fig. 18. Continued.

Table 1. Correlation coefficients for *P. tumifex* population levels at sites 2–5.

CORRELATIONS	STETSON	MONROE	EDINBURGH
U MAINE #2	.11 (.69)	.45 (.09)*	.77 (.001)*
STETSON	--	.53 (.06)*	.44 (.10)*
MONROE	--	--	.67 (.01)*

*significant at the 0.10 level (probability levels adjusted by the number of comparisons that were made, Bonferroni probability level).

Table 2. Correlation coefficients for *D. balsamicola* population levels at sites 2–5.

CORRELATIONS	STETSON	MONROE	EDINBURGH
U MAINE #2	.27 (.47)	.52 (.09)*	.53 (.09)*
STETSON	--	.71 (.01)*	.72 (.10)*
MONROE	--	--	.89 (.001)*

*significant at the 0.10 level (probability levels adjusted by the number of comparisons that were made, Bonferroni probability level).

future populations. Appendix A contains the parameter estimates for the site and species specific models. Figure 18 contains forecasts for the last three years of each sites sampling, as well as future predictions for the years 1992–1995. Since the 95% confidence intervals of the forecasts were not included in the figure, it must be realized that for each successive forecast, the confidence region of the prediction becomes increasingly large. However, the trend of the population fluctuations is captured with an average periodicity between outbreaks of the midges being seven years.

GALL MORPHOLOGY

The morphology of the gall induced by P. tumifex is illustrated and described in detail by West and Shorthouse (1982). *P. tumifex* induces a simple, single-chambered, prosoplasmic gall on needles of the current year. Mesophyll cells proliferate and surround the larvae, and in the mature gall there is a thin layer of sclerenchyma tissue on the gall exterior. Enlarged vacuolate mesophyll cells compose most of the gall throughout its growth, and these modified mesophyll cells contain more starch than corresponding mesophyll cells in normal needles. The greatest concentration and largest starch granules are found in the thin-walled cells lining the base of the larval chamber. These are fed upon by the larva and are called nutritive tissue (West and Shorthouse 1982). The gall was considered to be mature by mid-July and starch became increasingly abundant as the gall matured, although there was a decrease in midseason. Starch granules disappeared from galls when the gall former dropped to the litter.

The inquiline, *D. balsamicola*, does not alter the gall structure and is assumed to feed on nutritive cells induced by *P. tumifex* (Shorthouse and West 1986).

CONTROL

Biological

Prior to the work of Osgood and Gagné (1978), many species of parasites were reported, presumably from the balsam gall midge, *D. balsamicola*. Giese and Benjamin (1959) reared *Tetrastichus marcovitchi* (Cwfd.) and *T. whitmani* (Grlt.) from balsam gall midge larvae in Wisconsin. Osgood and Dimond (1970) listed nine chalcidoid and proctotrupoid Hymenoptera associated with the midge in Maine and discussed some of their host relationships. Macgown and

Osgood (1972) reported on the taxonomy and biology of 17 chalcidoid and proctotrupoid Hymenoptera associated with the midge in Maine. MacGown and Osgood (1971a) described two new species of *Platygaster* parasitic on the gall midge, *Platygaster abicollis* MacG. and Osgd. and *P. mainensis* MacG. and Osgd. They also described a third new species of *Platygaster* which is probably a parasite of the balsam gall midge, *Synopeas osgoodi* MacG. (MacGown and Osgood 1974). MacGown (1979) described two new species of chalcid parasites of the balsam gall midge, *Tetrastichus cecidivorus* MacG. and *Pseudencyrtus borealis* MacG. A key to Hymenoptera associated with the balsam gall midge in Maine was published by MacGown and Osgood (1971b). An abbreviated key to species known as or strongly suspected of being parasites is included in MacGown and Osgood (1972).

Following the work of Osgood and Gagné (1978), Connor and Osgood (1979) reared the following parasites from larvae of the gallmaker, *P. tumifex*.

Chalcidoidea	
Eulophidae	*Tetrastichus marcovitchi* (Cwfd.)
	Tetrastichus cecidivorus MacG.
	Tetrastichus whitmani (Grlt.)
Encyrtidae	*Pseudencyrtus borealis* MacG.
Procototrupoidea	
Platygastridae	*Platygaster abicollis* MacG.& Osgd.
	Platygaster mainensis MacG. & Osgd.

No parasites were found on *D. balsamicola* in that study. The above list of six parasitic species are the same as the six species of major parasites listed by MacGown and Osgood (1972).

Information on the biology of these species was recorded by MacGown and Osgood (1972) and unless otherwise noted the following information is taken from that work.

T. marcovitchi—The life history of this species is shown in Fig. 19. It is an external parasite, eggs being laid singly in the gall. Adults were most abundant from June 30–July 4, 1969 and were collected from June 6 until the latter part of August There was considerable overlapping of adults, larval instars, and pupae in the field. Akar (1987) reared this species from larvae and pupae collected by dissecting galls in October and November. They completed eclosion

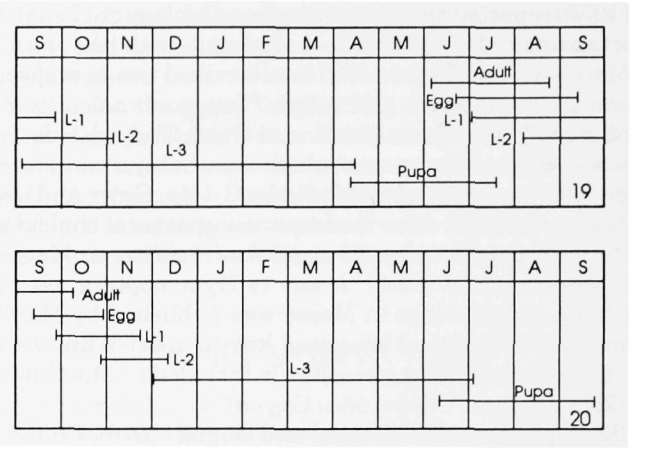

Fig. 19-20. Life history of *Tetrastichus marcovitchi* (Fig. 19) and of *T. cecidivorus* (Fig. 20) from field observations and laboratory rearings.

without prolonged exposure to low temperature thus showing a lack of an obligate diapause in this species.

T. cecidivorus—The life history is shown in Fig. 20, and life stages did not overlap as broadly as those of *T. marcovitchi*. It is an internal parasite, the egg being inserted beneath the host's cuticle. Third instar parasites nearly fill the host's integument. In 1969 adults were first collected September 20 and were abundant through early October

Akar (1987) used an emergence trap to collect adults of *T. marcovitchi* and *T. cecidivorus* as they emerged from the soil. Emergence peaked in July and September 1985, respectively. This is consistent with the sweeping data of MacGown and Osgood (1972). The male:female ratios of 71 *T. marcovitchi* collected in 1985 was 1:3.18, and of 117 collected in 1986 it was 1:2.25; pooled 1:2.55.

T. whitmani—adults were collected from early July through September 1969, but were not sufficiently abundant to gather additional biological data.

P. borealis—Adults were collected in 1969 from late June to mid-October but were not abundant.

P. abicollis and *P. mainensis*—These two species could not be differentiated in the larval stage and are treated together. Both species are early spring internal parasites, ovipositing in eggs and

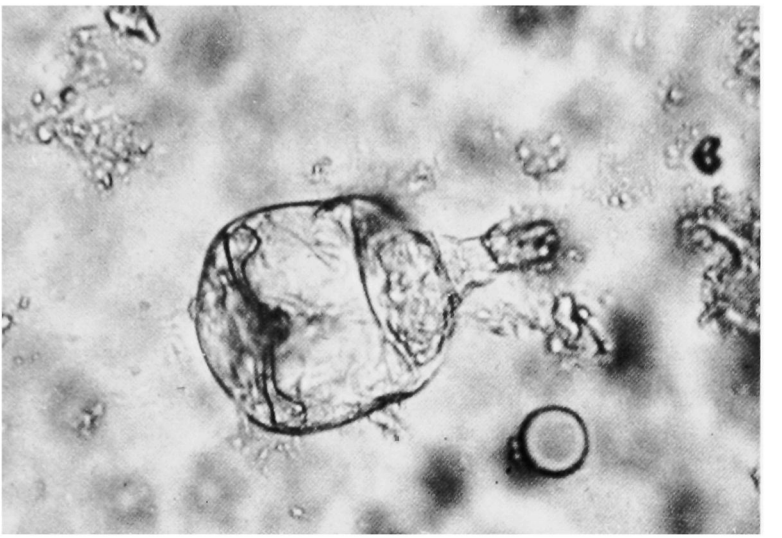

Fig. 21. *Platygaster*, 1st instar larva, 430X, removed from host.

early 1st instar midge larvae (before they are enveloped in the gall). In the 1969 study, they were collected from May 20 until mid-June. They were relatively abundant, populations reaching their peaks in early June. Emergence trap data of Akar (1987) showed that emergence of *P. abicollis* and *P. mainensis* continued throughout the emergence period of the host. The male:female ratio of 141 adult *P. mainensis* collected in 1985 was 1:2.44, and for 53 collected in 1986 it was 1:1.94, pooled 1:2.29. Eggs hatch 3–4 days after oviposition, giving rise to "cyclops-like" 1st instar larvae (Fig. 21). These persist until the following spring, but showed overall increases in size and widening of the space between the mandibles later in the summer (MacGown and Osgood 1972). Second and 3rd instars and pupation occured in quick succession the following spring. Singly parasitized midge larvae were most common, but five *Platygaster* / host were observed, two to three being common (Fig. 22).

Two other members of the Platygastridae, *Synopeas osgoodi* MacG. and *Inostemma* sp., may be parasites of the balsam gall midge, but more work is needed to verify this. Osgood and Dimond (1970) collected *S. osgoodi* ovipositing shortly after midge oviposition and *Inostemma* sp. was collected on newly galled needles. MacGown and Osgood (1972) also collected these platygastrids on fir. Neither species was abundant in either study, and no details of their life histories are known.

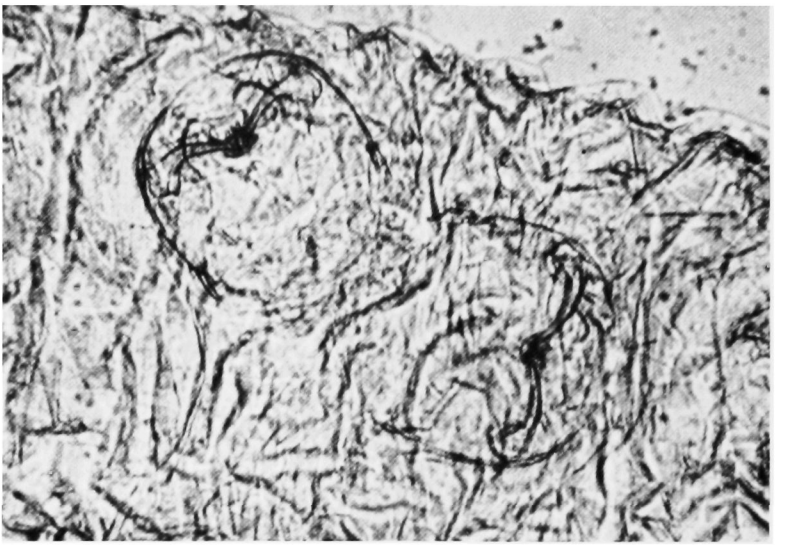

Fig. 22. Two 1st instar larvae of *Platygaster* within a single host. 430X.

MacGown and Osgood (1972) reported that Conklin (pers. comm. and loan of specimens 1970) recorded *Tetrastichus anthophila* Burks from balsam gall midge in New Hampshire. This species has not been collected in Maine studies.

No definitive work on rates of parasitism that includes all species has been done. Osgood and Dimond (1970) reported 5–23% parasitism rates in widely separated areas in Maine, and this did not include Platygastridae. Giese and Benjamin (1959) recorded 80% in Wisconsin. MacGown and Osgood (1972) recorded 50% parasitism in Maine. Their dissection data included parasitism by four species, *T. marcovitchi, T. cecidivorus, P. abicollis,* and *P. mainensis*. Parasites in order of abundance determined by sweep net collections in their study were *T. marcovitchi,* (most abundant), *Platygaster* spp., *Pseudencyrtus borealis, T. cecidivorus,* and *T. whitmani,* (least abundant). Parasitism rates would be expected to vary widely from one year or one site to the next and with fluctuations in the midge host population. This was shown by Struble (1974). His work was carried out at much lower midge host densities than that of MacGown and Osgood (1972). Struble's data showed that *T. whitmani* was the most abundant followed in order by *T. marcovitchi, T. cecidivorus,* and *Platygaster* spp.

Predation on larvae in the needle gall of balsam fir was noted in one area by Struble and Osgood (1976). Galls that had been torn

Fig. 23–24. 23, damage on a double-galled needle; 24, branch showing a high incidence of predation.

open (Fig. 23) were noted November 15, 1971. Predation was 29% in one plot and 39% in another. The midge population was low in 1971, and mortality from this type of predation was much higher than that of the entire parasite complex. Branch samples containing galled needles that were located by the predator were highly preyed upon (Fig. 24). Struble and Osgood were unable to determine the kind of predator at that time. During the first part of November 1990 John Dimond (pers. comm.) noted several black capped chickadees, *Parus atricapillus* Linn., searching and pecking at current-year needles of balsam fir containing the needle galls. Damage caused to the galls was observed by the senior author and was similar to that shown in Figs. 23–24. Subsequently, the senior author observed this behavior and damaged galls several times. In November only the inquiline is present in the galls, but we assume that some of the damage occurs earlier in the season, and that the gallmaker is also preyed upon.

In October of 1985 and 1986 Akar (1987) observed mites preying on third instar *P. tumifex* larvae, on leaf litter and in drop trays used to collect larvae. They were identified as post larval *Allothrombium* sp. (Acarina-Thrombiidae). *Allothrombium* has previously been reported being an active predator of a wide array of invertebrates, but this was the first known instance of predation on dipterous larvae.

Giese and Benjamin (1959) reported that a balsam needle rust, *Milesia marginalis* Faull. and Wats., indirectly killed midge larvae. Bergdahl and Mazzola (1985) studied the competitive relationships between *P. tumifex*, *D. balsamicola*, and a rust fungus, *Uredinopsis mirabilis* (Peck) Magnus, on balsam fir needles. All needles infected with *U. mirabilis* died. Abscission of infected needles began about July 21, and all infected needles dropped by September 1, 1983. *U. mirabilis* indirectly caused mortality of *P. tumifex* and *D. balsamicola*. Mortality began the first part of July and was 100% by August. This rust also causes indirect mortality of parasites of *P tumifex*.

From the preceding it is evident that the balsam gall midge, *Paradiplosis tumifex*, faces a formidable array of natural enemies. The inquiline *Dasineura balsamicola* and the chalcidoid and prototrupoid parasites cause the most mortality.

Silvicultural

MacGillivray et al. (1971) found that balsam fir, *Abies balsamea* (L.) Mill. was more frequently attacked than other species of non-native firs of about the same age growing in adjacent rows in a plantation in New Brunswick, Canada. They compared balsam fir

to Nikko fir, *A. homolepis* Sieb. and Zucc.; Korean fir, *A. koreana* Wil.; white fir, *A. concolor* (Gord. and Glend) Lindl.; Siberian fir, *A. sibirica*, Ledeb.; grand fir, *A. grandis*, (Dougl.) Lindl.; and Fraser fir, *A. fraseri* (Pursh) Poir. No galls were found on Nikko fir in two successive years, but were common on adjacent balsam fir. As mentioned previously the balsam gall midge oviposits under loosened bud scales or in newly opening buds of balsam fir, and the adult activity period is approximately two weeks. Nikko fir did not begin flushing its needles until July 3, so all adult midge oviposition had probably ceased prior to that time. No data were obtained on the phenology of needle flushing for Siberian fir, but grand, white, Fraser, and Korean fir averaged 8, 8, 18, and 18 days later than for balsam. MacGillivray et al. (1971) suggested that Nikko fir was immune to attack because of late bud break. The reason for the lower percentage of attack on other species of firs was obscure. They did find that larvae matured and left galls of Fraser and Korean fir, and from data on midges on Douglas-fir and the balsam gall midge discussed subsequently, we feel that late bud break may have been the cause for reduced attack on Fraser and Korean fir.

Mitchell and Nagel (1969) studied a complex of needle mining midges on Douglas-fir composed mostly of one species, *Contarinia pseudotsugae* Condrashoff. These midges also lay their eggs on newly opening buds, and on average 16 fewer needles were mined for each day of delayed bud burst. But they also found that there was a considerable difference in the degree of needle mining between individual trees for any single bud burst date. They concluded that infestations of these *Contarinia* spp. could be mostly avoided by culturing late bud burst trees.

Similar studies, unreported to date, were carried out in Maine on the balsam gall midge in 1970–71 by the senior author. In 1970 the date of bud burst (green of bud exposed) was determined for 121 naturally seeded balsam fir trees in a moderately infested Christmas tree stand in Franklin, Maine. Bud burst for seventeen of these trees, varying from earliest to latest, was determined again in 1971. Females were observed ovipositing from May 15–27, 1970, but none were seen on May 31. Two current-year shoots per tree were examined on July 24, and the numbers of galls on each was recorded.

Bud burst in trees is genetically controlled. A 20-day range of bud burst dates was recorded in 1970, and those bursting early or late in 1970 did so in 1971. Buds that burst prior to May 31 contained 8.2 galls per shoot (108 trees), and buds bursting on May 31 or later (14 trees) had 3.9 galls per shoot, a 52.5% reduction. Buds on three trees did not burst until June 3. These contained 0.33 galls/shoot, a

96% reduction. Two of these three trees were observed closely in 1971 and had normal foliage and good form and growth rate when compared to other trees in the plantation. Culturing late bud burst trees would prevent infestations of balsam fir by the balsam gall midge. Indeed one of the selection criteria included in the Maine Christmas Tree Growers Association seed orchard was late bud break. This variable was selected to reduce the susceptibility of the trees to balsam gall midge and frost damage. Seed and scions have been collected from late flushing trees, but it will be several years before the progeny can be evaluated for superior traits.

The level of midge infestation varied greatly for any single bud burst date. Several of the earlier bud bursters that appeared to be in the ideal stage of development for midge oviposition were uninfested. In some instances such trees were observed to have short, yellower needles which may have affected midge oviposition preference, but in most instances the reason for the lack of attack was obscure.

Chemical

No formal survey method to determine the need for chemical control has been developed to monitor balsam gall midge populations within plantations. In the early stages of an outbreak, midge attack is very scattered. Sampling techniques would need to be very extensive to ensure collecting from the scattered susceptible trees.

A survey procedure was developed to estimate needle loss (Giese and Benjamin 1959). The procedure utilized one plot of four trees per each five acres of plantation. Ten apical tips from each of four branches per tree were selected for examination. The number of galled needles per tip was counted and recorded, as well as an estimate of the needles remaining on the two- and three-year-old internodes. Estimates on the old foliage are based on leaf scars left by a previous infestation. This survey is carried out in July or August. Giese and Benjamin also presented data on the correlation of multiple galls and the level of infestation. These procedures were developed to allow growers to anticipate the level of defoliation and prevent damaged trees from being marketed. This method does not allow growers to anticipate damaging population levels of the midge within their plantations.

Midge populations usually adversely affect less than five percent of trees within a stand the first year of a population increase. Control is not essential at this stage, but due to the cyclic nature of this insect, control measures will probably be required the following year. Managers should train themselves to recognize the galls while

performing other cultural tasks within the stand. Early detection will allow preparation for a control program the following year. Annual control programs are entirely unnecessary if field managers and assistants learn to detect the galls and develop some confidence in their ability to find them. The necessity of a spray program should be confirmed in the spring of the year of treatment by observation of adults during nuptial and oviposition flights.

Chemical control of the balsam gall midge is frequently required to prevent defoliation in balsam fir plantations that are being managed for quality Christmas trees and wreath brush. Discoloration and early abscission of needles infested by the midge reduce the quality of trees. In years of high population density, entire plantations may be rendered unmarketable representing economic losses often in excess of $15,000 per acre. Christmas trees can be recovered by shearing and two more years of undamaged growth, but the extension of the rotation period is very undesirable. Damage is rarely significant in natural stands managed for pulpwood production and chemical control measures are not used in these situations. The midge is not reported to cause mortality because parasites, predators, and the inquiline appear to limit the duration of infestations in any specific area. Galled needles remain on the twig throughout the growing season and are assumed to continue to contribute nutrients to the tree.

An array of efficacy trials against the balsam gall midge have been conducted since the mid-1950s using a range of insecticides, (Appendix B). Trunk implants of systemic insecticides, were found to be effective (Giese et al. 1958), but the method is cumbersome and does not lend itself to projects involving more than a few trees.

Early foliar treatments were directed at adults and eggs and provided variable levels of control. Giese and Benjamin (1959) obtained no control using foliar applications of DDT or dieldrin. Foliar application of lindane, malathion, or DDT concentrates were effective when applied with compressed air 'garden type' sprayers, while DDT or malathion dusts were not effective in similar testing in Maine (Dimond 1959).

Dimond suggested timing the application of pesticides to contact 1st instar larvae as a better approach to midge control. Ground applications directed at newly forming galls using Cygon 2.67 or Malathion 57ec applied with compressed air sprayers or knapsack mistblowers were successful (Dimond and Osgood 1970). An aerial trial of Cygon 2.67 was included in this project, but it did not provide acceptable midge control. The authors stressed that new galls were visible before application of the insecticide. When larvae

were killed, gall growth was arrested after treatment, and needles did not abscise early.

Field trials from 1970 on used powered equipment only to obtain more efficient coverage of the large plantations planted to meet the needs for an expanding Christmas tree market. A hydraulic sprayer with a 50-gal. tank operating at 300 psi with several insecticides provided control (Saunders and Harrigan 1976). The authors recommended only diazinon or malathion because the remaining products were ineffective, highly toxic, or lacking suitable registration. Diazinon and Cygon were both applied to control the midge using either a backpack mistblower or a helicopter (Osgood 1977). The Cygon trials failed, but diazinon proved effective and was registered in Maine. Reduced rates of diazinon or chlorpyrifos were found to be effective when applied with a backpack mistblower (Bradbury and Osgood 1987). Several pyrethroids were also tested in that trial, but all failed to provide acceptable levels of control.

Timing of chemical application is critical for effective control of the midge and should be timed to coincide with the elongation and flattening of the shoot. This permits the insecticide to contact the basal portion of the needle where the larvae are located. Gall formation begins by this time, and small flat galls often can be seen prior to spraying. Bradbury and Osgood (1987) achieved high levels of control with single applications at five- to seven-day intervals

Fig. 25. Undeveloped (top) and developed (bottom) galls on balsam fir caused by larvae of the balsam gall midge.

beginning when galls had just begun to form. The third application of this series was directed toward well-developed galls, but still provided good control. Gall development was arrested in all cases where the larvae were killed, and galled needles remained on the twigs throughout the year (Fig. 25).

The balsam gall midge can have a serious economic affect on firs being cultured for Christmas trees or wreath material because of defoliation resulting from early abscission of needles. Diazinon or chlorpyrifos applied at 0.25–0.75 lb. A.I. per acre with a mistblower (Bradbury and Osgood 1987) and diazinon applied aerially (Osgood 1977) are very effective control techniques when required. Frequent observation of plantations will allow growers the time to prepare control measures for the following year if a rise in population is noted. Any future work to produce an effective and cost-efficient survey method for this insect would fill a gap toward further reduction of unnecessary pesticide usage.

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APPENDIX A

The parameter estimates for the following model form:

$$N_{(t+1)} = b_1N_{(t)} + b_2N_{(t-1)} + b_3N_{(t-2)} + a_t, \text{ where } a_t = N_{(t)} - N_{(t-1)}(1),$$

are presented in the table below for the midge species and location:

	$b_1 \pm$ se	$b_2 \pm$ se	$b_3 \pm$ se
P. tumifex			
U of Maine #2	0.824 ± 0.50	0.528.± 0.33	-0.486 ± 0.33
Stetson	0.073 ± 0.22	-1.830 ± 0.36	0.738 ± 0.16
Monroe	1.905 ± 0.73	-1.470 ± 0.81	0.484 ± 0.71
Edinburgh	0.338 ± 0.13	0.416 ± 0.15	-0.246 ± 0.12
D. balsamicola			
U of Maine #2	0.218 ± 0.13	0.287 ± 0.12	-0.586 ± 0.13
Stetson	0.169 ± 0.12	-0.054 ± 0.14	-0.330 ± 0.14
Monroe	0.241 ± 0.15	-0.232 ± 0.16	-0.360 ± 0.16
Edinburgh	0.595 ± 0.17	-0.640 ± 0.15	0.071 ± 0.05

APPENDIX B

Chronology of insecticide efficacy trials against balsam gall midge, *Paradiplosis tumifex*.

Date	Researcher	Application[1] Method	Application[2] Timing	Insecticide	Result[3]
1958	R.L. Giese,	1	LL	Demeton	A
	D.M. Benjamin,	1	LL	Thimet	U
	J.E. Casida	1	LL	Dimefox	U
		1	LL	R-6199	U
		1	LL	Am.Cyan.12880	A
1959	J.B. Dimond	2	A,E	DDT Ec	A
		2	L1	Lindane Ec	A
		2	L1	Malathion Ec	A
		3	A	DDT Ec	U
		4	A	DDT dust	U
		4	A	Malathion dust	U
1959	R.L. Giese	? foliar	A,E	DDT	U
	D.M. Benjamin	? foliar	A,E	Dieldrin	U
1970	J.B. Dimond	2	L1	Malathion 57 Ec	A
	E.A. Osgood	2	L1	Cygon 2.67	A
		3	L1	Malathion 57 Ec	A
		5	L1	Cygon 2.67	U
1976	J.L. Saunders	6	E,L1	Diazinon	A
	W.R. Harrigan	6	E,L1	Chlorpyrifos	A
		6	E,L1	Malathion	A
		6	E,L1	Carbofuran	A
		6	E,L1	Carbaryl	U
		6	E,L1	Trichlorfon	U
		6	E,L1	Meta-Systox-R	U
		6	E,L1	Endosulfan	U
		6	E,L1	Lindane	U
		6	E,L1	Imidan	U
		6	E,L1	Acephate	U
		6	E,L1	Phosalone	U
		6	E,L1	Propoxur	U
1977	E.A. Osgood	3	L1	Diazinon AG500	A
		3	L1	Cygon 2.67	U
		5	L1	Diazinon AG500	A
		5	L1	Cygon 2.67	U
1987	R.L. Bradbury	3	L1	Diazinon AG500	A
	E.A. Osgood	3	L1	Chlorpyrifos	A
		3	L1	Permethrin	U
		3	L1	Fenvalerate	U

[1]1 Systemic trunk implants, 2 Knapsack hydraulic sprayer, 3 = Backpack mistblower, 4 = Rotary duster, 5 = Aerial—helicopter, 6 = Powered hydraulic—300 psi

[2]A = adult, E = egg, L1 = 1st instar larval, LL = later instar larvae

[3]A = acceptable control, U = unacceptable control