# TIP MOTH PARASITOIDS AND PESTICIDES: ARE THEY COMPATIBLE?

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**Abstract**—Effects of herbicide and insecticide applications on parasitism of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) were examined in 2-yr-old loblolly pine (*Pinus taeda* L.) plantations in Georgia. Total parasitism rates varied significantly among tip moth generations, but there were no differences in parasitism rates between herbicide-treated and untreated plots. Significant differences in the relative abundance of parasitoid species were found among generations, with *Eurytoma pini* Bugbee being the most common in summer and *Lixophaga mediocris* Aldrich the most abundant in spring. Plots treated with the insecticide, Orthene, had significantly less parasitism than plots treated with tebufenozide, *Bacillus thuringiensis* var. *kurstaki*, or untreated check plots. Effects of acephate treatments were species-specific, with no apparent effects on parasitism by *L. mediocris* Aldrich but significantly decreased parasitism by *Haltichella rhyacioniae* Gahan.

## INTRODUCTION

Damage caused by the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) is highly variable, and may be negligible or high enough to cause tree mortality. Large population fluctuations have been associated with common southern forest regeneration practices, which often include intensive site preparation, chemical control of competing vegetation, and fertilization to increase seedling growth (Miller and Stephen 1983, Nowak and Berisford 2000). The Nantucket pine tip moth has a high reproductive potential, which may be constrained to some degree by high parasitism rates (Eikenbary and Fox 1968a,b; Freeman and Berisford 1979; Wallis and others 1980; Gargiullo and Berisford 1983; Warren 1985; McCravy and Berisford 2000). Potential effects of forest management practices on tip moth parasitoids have received little attention. It has been suggested that natural enemies of herbivorous insects are more effective in diverse systems than in simple ones (Pimentel 1961). In a review of tests of this natural enemy hypothesis, however, Russell (1989) found the results to be inconclusive for parasitism.

Insecticidal control of tip moths may be necessary in intensively-managed commercial pine plantations. A number of "hard" pesticides such as acephate, an organophosphate, have been used successfully to control tip moth populations. However, organophosphates often cause high mortality among natural populations of parasitoids and predators as well (Croft 1990). Alternative insecticides, such as *Bacillus thuringiensis* var. *kurstaki* (Btk) and the insect growth regulator, tebufenozide, may be more compatible with tip moth natural enemies. In this paper we describe two studies investigating effects of herbicidal vegetation control and conventional and biorational insecticidal treatments on tip moth parasitism.

## MATERIALS AND METHODS

### Vegetation Control Study

This study was conducted in 1996–97 in three 2-yr-old loblolly pine plantations in the Georgia coastal plain. The plantations ranged from 44 to 70 ha. Two sites were located in Burke County, near Waynesboro, and one in Bulloch County, near Statesboro. Each site was mechanically prepared, and 1-0 bareroot improved loblolly pines were machine planted at densities of approximately 1492 trees per ha in the winter of 1994–95. In spring, 1996, each tract was divided approximately in half, with one randomly selected half receiving a herbicidal treatment of hexazinone and sulfometuron methyl at rates of 2.34 and 0.22 liters/ha, respectively. The remaining halves were left untreated. The Waynesboro sites were treated again in the fall, 1996 with imazapyr and glyphosate at 0.58 and 2.38 liters/ha, respectively. Herbicides were applied by helicopter at the Waynesboro sites and by tractor at the Statesboro site. In spring, 1996, 50 pines were randomly chosen in each treatment of each study site to serve as permanent study trees. Tip moth infestations were evaluated by counting numbers of infested shoots on the permanent study trees in each generation, when tip moths were in the late larval and pupal stages and damage was most obvious. Non-pine vegetation was quantified and characterized for each treatment plot as well. Twenty randomly located 1 $m^2$ quadrats were established in each plot at each site during each tip moth generation. For each quadrat, a visual estimate of percentage ground cover was taken, the maximum height of vegetation was measured, and presence or absence of flowering vegetation was recorded. Specimens of each plant species present were taken, returned to the laboratory, and identified to species. The spring, 1997 (1st)generation of the Statesboro site was not included in the study because of low tip moth populations.

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Collections of infested shoots for rearing of tip moths and parasitoids also were made during the late larval/pupal stages of each tip moth generation. In each treatment plot, 2,000 infested shoots were randomly collected from non-permanent study trees. Summer (2nd generation) 1996 collections were made on 26–27 June and 2–3 July at the Statesboro and Waynesboro sites, respectively. Late summer (3rd generation) 1996 shoots were collected on 7–8 August and 10–11 August, respectively. Collections of shoots for the overwintering (4th) generation were made in two stages. Half of the shoots were collected on 22 September and 26 September, 1996 at the Statesboro and Waynesboro sites, respectively, and half were collected on 16 January and 21 January, 1997. This was done in order to sample parasitoids that might emerge before the onset of tip moth pupal diapause as well as those emerging in late winter and early spring. Spring (1st generation) 1997 collections were made on 3–4 May at the Waynesboro sites. Because of low tip moth infestations for this generation, 1,000 shoots were collected from each treatment plot. Shoots were returned to the laboratory and placed in ventilated rearing containers (Berisford and others 1971), separated by site and treatment. Emerging adult moths and parasitoids were collected every 2–3 days. Moths were counted and parasitoids were counted and identified to species, if possible, using Yates' (1967) key, and placed in 70 percent EtOH. At the end of emergence for each collection, shoots were removed from the rearing cans, dissected, and examined for the presence of tip moths, parasitoids, or cocoons. Series of each apparent species were sent to appropriate taxonomic authorities for positive determinations. Tip moth parasitism rates were determined based on relative numbers of emerged parasitoids and moths. Two parasitoids, *Hyssopus rhyacioniae* Gahan and *Pteromalus* sp. Swederus, were determined to be gregarious based on dissection of individual tip moth-infested shoots, and averaged 12.2 $\pm$ 1.20 (mean $\pm$ SEM, $n$ = 15) and 2.92 $\pm$ 0.45 ($n$ = 12) individuals per brood, respectively. Total numbers of individuals reared for these two species were divided by these means to get a more realistic estimate of the number of parasitism events.

Parasitoids were also collected using malaise traps in order to get an estimate of the relative abundances of parasitoids in the herbicide-treated and untreated plots. Two traps, one in each treatment plot, were operated at the Waynesboro 1 and Statesboro sites for eight five-day trapping periods from mid-June to early October 1996. Traps were randomly relocated for each trapping period. Insects were collected in 70 percent EtOH. At the end of each trapping period, samples were taken to the laboratory and parasitoids, defined as Parasitica (Huber 1993) plus tachinids (Diptera), were removed and counted. Recognizable tip moth parasitoids were also separated and counted.

Numbers of infested shoots and parasitism rates were each compared between treatments and among generations and sites using 3-way analysis of variance, with Tukey's multiple comparisons test. Relative variation in infestation levels and parasitism rates for each treatment, pooled across site and generation, was measured using the coefficient of variation (Sokal and Rohlf 1995). Comparison of proportions of *H. rhyacioniae* reared from tip moth-infested shoots collected from herbicide-treated vs. untreated plots was made using paired *t*-tests. Numbers of parasitoids captured in malaise traps were compared between treatments and sites using 2-way analysis of variance. All analyses were performed using the SigmaStat Version 2.0 software package (Jandel Scientific Software 1995).

## Insecticide Study

This study was conducted in a 2-yr-old loblolly pine plantation, of approx. 80 ha, in Taylor Co., GA. Pines ranged from 0.6 m to 1.2 m in height. Tip moth populations were high, with a shoot infestation rate of approx. 66 percent in the top whorl of branches for the 1st generation. Sprays were timed for optimum efficacy with a degree-day timing model developed using an organophosphate insecticide (dimethoate) for the Nantucket pine tip moth (Garguillo and others 1985). Moth flight was monitored with four wing traps (Pherocon 1C® baited with Nantucket pine tip moth lures (Trece Inc., Salinas, CA). Upon initiation of the summer (2nd) tip moth generation, degree-days were accumulated with a continuously recording biophenometer.

The study was set up as a randomized complete block design, with two replicates (blocks) per treatment and untreated control, for a total of eight plots. Plots were rectangular and 2.8 ha. Blocks were approximately 30 m apart, and plots were a minimum of 150 m apart. Acephate (10.8 percent [AI]), Btk (100 percent [AI]), and tebufenozide (2.0 percent [AI]) were used as treatments. Acephate and tebufenozide were applied at a rate of 4.6 liters/ha, while Btk was applied undiluted at 0.77 liters/ha.

Applications were made by helicopter with a 9.1 m air foil simplex boom and spray system. Acephate and tebufenozide were delivered at a rate of 68.9 liters/min. Btk was sprayed at 11.7 liters/min. Acephate and tebufenozide were applied on the evening of 3 June 1998. Wind speed was 0–5 km/h, and temperature and relative humidity were 30° C and 66 percent, respectively. Btk was sprayed in the early morning on 4 June 1998. Wind speed was 0–8 km/h, and temperature and relative humidity were 25° C and 99 percent, respectively. Coverage was monitored by deploying 10 water sensitive cards in each spray plot.

Insecticide efficacy was evaluated on 50 randomly selected trees in each plot by assessing percentage infestation of shoots in the top whorl after moths had reached the late larval/pupal stages, in early July. At that time, approx. 500 damaged shoots were randomly collected from the interior 1.2 ha of each plot for rearing of adult moths and parasitoids. Most tip moth parasitoids are koinobionts and emerge from late larvae and pupae of the moths. Shoots were placed in ventilated rearing containers (Berisford and others 1971). Emerging adult tip moths and parasitoids were collected weekly and stored in 80 percent EtOH.

Treatment effects on overall parasitism rates were analyzed using 2-way analysis of variance with Tukey's multiple comparison test. Variation in contribution of individual parasitoid species to overall parasitism between each treatment and control was examined using the chi-square test of independence (Sokal and Rohlf 1995). Species-specific differences were evaluated by comparing cellspecific contributions to the overall chi-square to a critical value of 3.841, using a one-degree-of-freedom criterion at an alpha value of 0.05 (Freeman 1987). All statistical analyses were done using SigmaStat, version 2.0 (Jandel Scientific Software 1995).

## RESULTS

### Vegetation Control Study

The most common plant species found (during sampling months in which flowering individuals were present) are shown in Table 1. Total vegetation was greater in untreated than herbicide treated plots for all three parameters measured, pooled across site (table 2).

Percent shoot infestation was higher in the untreated plots (10.517 ± 0.958) than in the treated plots (2.992 ± 0.494) ($F$ = 121.731; df = 1,6; $P$ < 0.001). Percent shoot infestation among generations ranged from 5.372 ± 1.521 for the late summer generation to 8.703 for the winter generation, and were marginally nonsignificant ($F$ = 4.681; df = 3,6; $P$ = 0.052). Infestation rates among sites ranged from 5.924 ± 1.545 for the Waynesboro 1 site to 7.605 ± 2.121 for the Waynesboro 2 site, with no significant differences ($F$ = 2.027; df = 2,6; $P$ = 0.213) There were no significant interaction effects. Relative variation in infestation levels was much greater in treated than untreated plots (CV = 57.18 percent vs. 32.89 percent, respectively).

Mean tip moth parasitism rates were 51.0 percent ± 6.61 percent and 48.2 percent ± 6.17 percent in the herbicide-treated and untreated plots, respectively. Rates were not significantly different between treatments ($F$ = 1.17; df = 1, 6; $P$ = 0.321). Parasitism rates were different among sites ($F$ = 22.91; df = 2, 6; $P$ = 0.002) and generations ($F$ = 92.90; df = 3, 6; $P$ < 0.001). Rates were significantly higher at Statesboro than at the Waynesboro sites. Rates of parasitism were highest in the spring and summer generations and lowest in the winter (fig. 1). There were no significant interaction effects. Relative variation in parasitism rates was similar in treated and untreated plots (CV = 43.02 percent vs. 42.46 percent, respectively).

Overall, 9,629 parasitoids were reared, representing 4143.5 parasitism events and 19 species in nine families. Three parasitoids, *Lixophaga mediocris* Aldrich, *Eurytoma pini* Bugbee, and *Hyssopus rhyacioniae* Gahan accounted for over 70 percent of total parasitism. *Eurytoma pini* was the most abundant species in the summer, but was relatively rare in winter and spring (fig. 2). *Lixophaga mediocris* was by far the most abundant species in the spring. *Hyssopus rhyacioniae* accounted for a greater mean proportion of parasitism in herbicide-treated (19.35 percent) than untreated (11.58 percent) plots ($t$ = 2.269, df = 10, $P$ = 0.047).

Malaise trapping resulted in 5,550 total parasitoid captures. Mean numbers of captures per trapping period were 177.19

**Table 1—Common plant species found in quadrat sampling and month in which flowering individuals were found**

| | Collection Date | | | |
|---|---|---|---|---|
| Family, Genus, and Species | Jun 1996 | Aug 1996 | Oct 1996 | Apr 1997 |
| Asteraceae | | | | |
| *Eupatorium capillifolium* (Lamarck) Small | | | + | |
| *Gnaphalium obtusifolium* L. | | + | + | |
| *Solidago* sp. L. | | | + | |
| Caryophyllaceae | | | | |
| *Cerastium glomeratum* Thuillier | | + | | |
| Cyperaceae | | | | |
| *Cyperus retrorsus* Chapman | | + | | |
| Fabaceae | | | | |
| *Stylosanthes biflora* Britton, Sterns, and Poggenburg | + | + | | |
| *Tephrosia spicata* (Walter) Torrey and Gray | | + | | |
| Hypericaceae | | | | |
| *Hypericum denticulatum* Humboldt, Bonpland, and Kunth | | + | | |
| Liliaceae | | | | |
| *Smilax* sp. L. | + | | | |
| Passifloraceae | | | | |
| *Passiflora incarnata* L. | + | | | |
| Polygonaceae | | | | |
| *Rumex crispus* L. | | | | + |
| Rosaceae | | | | |
| *Rubus argutus* Link | | | | + |
| Vitaceae | | | | |
| *Vitis rotundifolia* Michaux | + | | | |

**Table 2—Percent ground cover, maximum height, and frequency of occurrence of flowering individuals in herbicide-treated and untreated plots for four generations averaged over two (spring generation) or three (all other generations) study sites**

| Generation | Treatment | Ground cover | Maximum height | Frequency of flowering plants |
|---|---|---|---|---|
| | | *Percent* | *Cm* | *Percent* |
| Summer | Treated | 21.4 ± 2.6 | 35.2 ± 6.7 | 21.7 ± 3.3 |
| | Untreated | 51.3 ± 10.4 | 67.5 ± 16.8 | 40.0 ± 18.9 |
| Late Summer | Treated | 48.5 ± 3.3 | 58.2 ± 6.3 | 65.0 ± 7.6 |
| | Untreated | 71.8 ± 0.9 | 85.1 ± 17.8 | 95.0 ± 5.0 |
| Winter | Treated | 28.6 ± 9.6 | 60.2 ± 12.8 | 16.7 ± 12.0 |
| | Untreated | 60.7 ± 8.8 | 101.4 ± 13.2 | 76.7 ± 14.5 |
| Spring | Treated | 20.4 ± 5.5 | 23.6 ± 12.2 | 30.0 ± 5.0 |
| | Untreated | 49.8 ± 8.8 | 62.9 ± 7.9 | 70.0 ± 5.0 |
| Totals | Treated | 30.6 ± 4.4 | 46.2 ± 6.2 | 33.6 ± 7.1 |
| | Untreated | 59.2 ± 4.4 | 80.7 ± 7.4 | 70.5 ± 8.7 |

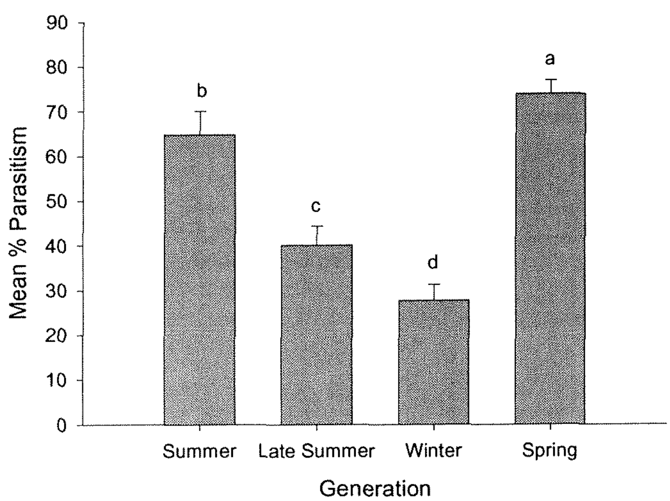


Figure 1—Mean percent tip moth parasitism (± SE) for four generations in the southeastern Georgia coastal plain. Means with the same letter are not significantly different ($P < 0.05$, Tukey's multiple comparison test).

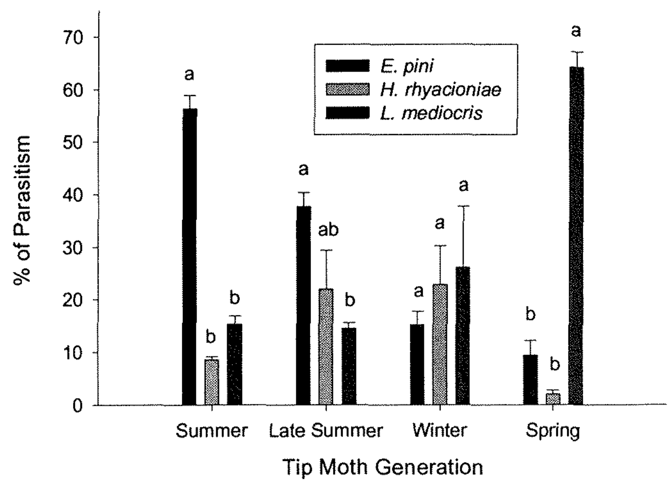


Figure 2—Mean percent of total tip moth parasitism (± SE) due to three parasitoid species for four generations in the southeastern Georgia coastal plain. Means with the same letter within a generation are not significantly different ($P < 0.05$, Tukey's multiple comparison test).

± 32.08 in the herbicide-treated plots and 169.69 ± 22.67 in the untreated plots, pooled across site, and did not differ between treatments or sites ($F = 0.0345$; df = 1,28; $P = 0.854$ and $F = 0.407$; df = 1,28; $P = 0.529$, respectively). A total of 252 known *R. frustrana* parasitoids were captured. Mean numbers captured per trapping period were 8.56 ± 1.73 in the herbicide-treated plots and 7.19 ± 1.20 in the untreated plots, pooled across site. There were no differences in captures between treatments ($F = 0.403$; df = 1,28; $P = 0.531$) or sites ($F = 0.333$; df = 1,28; $P = 0.568$). *Lixophaga mediocris* (70 percent of total) and *E. pini* (14 percent of total) were the most common species captured.

## Insecticide Study

Mean percent tip moth infestations in the top whorl of shoots were 48.2 ± 3.11, 29.55 ± 5.59, 33.25 ± 8.27, and 34.85 ± 8.27 for the control, acephate, tebufenozide, and Btk plots, respectively. A total of 465 parasitoids and 723 adult tip moths were reared, for a parasitism rate of 39.14 percent. Parasitism rates differed significantly among treatments ($F = 19.601$: df = 3,3; $P = 0.018$) (fig. 3). The parasitism rate in the acephate treated plots was about half that in the check, Btk, and tebufenozide plots. There were no significant differences among the check and the latter two treatments.

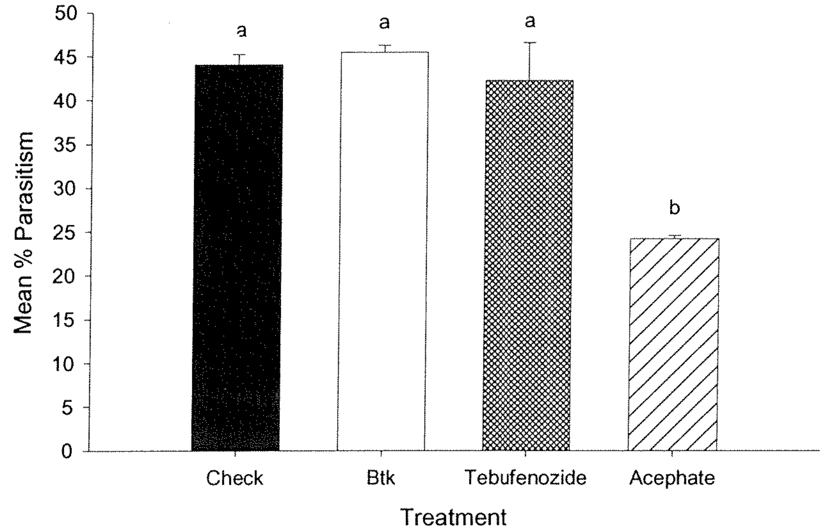


Figure 3—Mean percent tip moth parasitism (± SE) in three insecticide-treated *P. taeda* plots and an untreated check plot. Means with the same letter are not significantly different ($P < 0.05$, Tukey's multiple comparison test).

Fourteen species of parasitoids were reared. Of these, *E. pini*, an undescribed species of *Temelucha* Foerster (Hymenoptera: Ichneumonidae), *Haltichella rhyacioniae* Gahan (Hymenoptera: Chalcididae), and *L. mediocris* were the most abundant species, accounting for 89.9 percent of the total. Relative proportions of parasitism attributable to these four species differed significantly ($X^2 = 22.22$; df = 3; $P < 0.001$). This difference was primarily due to fewer *Ha. rhyacioniae* than expected ($X^2 = 3.993$; df = 1; $P < 0.05$) and more *L. mediocris* than expected ($X^2 = 8.681$; df = 1; $P < 0.005$) in the acephate treatment plots (fig. 4).

## DISCUSSION

Jervis and others (1993) found plants in the families Umbelliferae and Compositae to be the most frequently visited by parasitic Hymenoptera. Among the common plants found in our study, none were Umbellifers, but three (*Eupatorium capillifolium* (Lam.) Small, *Gnaphalium obtusifolium* L., and *Solidago* sp. L.) were composites (Asteraceae, table 1). In a study of flower associations of *Scambus buolianae* (Hartig) (Hymenoptera: Ichneumonidae), a parasitoid of the European pine shoot moth, *R. buoliana* (Schiffermüller), Leius (1963) found that

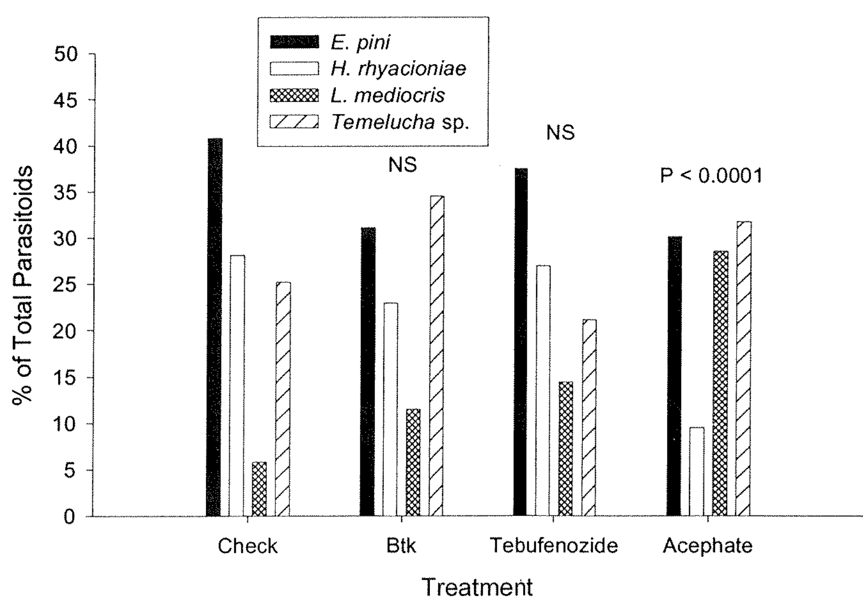


Figure 4—Relative proportions of tip moth parasitism due to four parasitoid species in three insecticide-treated *P. taeda* plots and an untreated check plot. NS = not significant.

wasps fed pollen of *S. canadensis* L. lived significantly longer than control wasps fed a sucrose solution. Likewise, Syme (1975) found increased longevity of female *Hyssopus thymus* Girault (Hymenoptera: Eulophidae) which had been exposed to the plants *Rumex acetosella* L. (Polygonaceae) and *Hypericum perforatum* L. (Hypericaceae), with exposure to *R. acetosella* also increasing fecundity. These results suggest that *R. crispus*, *H. denticulatum*, and *Solidago* sp. found in our study are potentially important food sources for *R. frustrana* parasitoids.

Past studies have found intensive forest management practices to be associated with increased tip moth population fluctuations (Miller and Stephen 1983, Nowak and Berisford 2000). Our study supported these results, with infestation levels nearly twice as variable in treated plots than in untreated plots, based on the coefficient of variation. Further study is needed to verify this association and to examine possible underlying causes.

The overall tip moth parasitism rate of ca. 50 percent found in the vegetation control study generally agrees with those of Freeman and Berisford (1979) (42 percent) for the Georgia piedmont and Eikenbary and Fox (1965) (41 percent) for the South Carolina coastal plain, but is higher than that obtained by the latter authors for the South Carolina piedmont (26.0 percent). Among individual species, *Hy. rhyacioniae* accounted for a significantly greater proportion of parasitism in the herbicide-treated than the untreated plots. This species may be less affected by microclimatic influences than the others, or may be less subject to competition or predation in the herbicide-treated plots. Tip moth infestation rates were about 3.5 times higher in the untreated plots than in the treated plots, but there was no significant difference in parasitism rates between treatments, indicating that more parasitism events occurred in the untreated plots. Malaise trapping showed no difference in parasitoid abundance between plots, suggesting a greater number of moths parasitized per parasitoid in the untreated plots, a functional response first described by Holling (1959). This response could result from greater longevity of parasitoids due to more food resources, less searching time per host due to higher moth densities, or other factors. However, the much higher infestation levels in the untreated stands suggest that vegetation management practices do not necessarily affect the role of parasitoids in tip moth population control.

The biological insecticides Btk and tebufenozide appeared to have no effect on tip moth parasitism. The effects of acephate were species-specific, with decreased parasitism by *Ha. rhyacioniae* and relatively high parasitism by *L. mediocris*. *Lixophaga mediocris* is a primary tip moth parasitoid (Freeman and Berisford 1979). Generally, *Lixophaga* spp. parasitize stem borers by ovipositing at openings made by the host. Larvae burrow through the host's frass and actively search for the host (Wood 1987). This suggests that *L. mediocris* attack late instar tip moth larvae, otherwise its eggs and larvae would be susceptible to early application of a contact insecticide such as acephate. *Lixophaga mediocris* adults are much larger and more robust than adults of the three common parasitic wasps captured in this study; this suggests that adults may be more capable of surviving contact with insecticides because of less surface to volume ratio. *Lixophaga mediocris* has been found to be most abundant in overwintering and spring tip moth generations in the Georgia coastal plain (McCravy and Berisford 2000). Thus, acephate would probably have less of an impact on overall tip moth parasitism during these generations.

*Haltichella rhyacioniae* has been found to be a primary parasitoid of tip moths in most studies, although one individual was reared from *L. mediocris* by Freeman and Berisford (1979). The low numbers of *Ha. rhyacioniae* in acephate-treated plots suggest that this parasitoid may be susceptible to this insecticide, either in the adult stage or perhaps as a result of larval mortality if it attacks tip moths in the early (targeted) larval stages. *Haltichella rhyacioniae* are small chalcidids, from 2.8 to 3.6 mm in length (Yates 1967), and their small size may contribute to their vulnerability to acephate. The timing of attack of *Ha. rhyacioniae* is unknown. This parasitoid is usually not a numerically important part of the tip moth parasitoid fauna, accounting for less than 10 percent of tip moth parasitism in most regions (Eikenbary and Fox 1965, Freeman and Berisford 1979, Lashomb and others 1980, Miller and Stephen 1983, McCravy and Berisford 2000), so high mortality of this species might not have a great impact on tip moth parasitism. The collection of large numbers of the undescribed species of *Temelucha* was surprising, given the numerous rearings of tip moth parasitoids done throughout much of the moth's range. This suggests that the species composition of the tip moth parasitoid complex can vary substantially even over relatively small geographic ranges. This finding further illustrates that there is still much to be learned regarding the parasitoid complexes of even relatively well-studied and economically important forest insect pests.

Little work has been done regarding the effects of tebufenozide on parasitoids. Jacas and others (1995) found that oral doses reduced survival of *Opius concolor* Szepl. (Hymenoptera: Braconidae) in a dose-dependent manner, but had no effect on fertility. Tebufenozide treatment of Mediterranean flour moth (*Ephestia kuehniella* Zeller) (Lepidoptera: Pyralidae) eggs parasitized by *Trichogramma pretiosum* Riley (Hymenoptera: Trichogrammatidae) did not significantly increase wasp mortality but did significantly reduce subsequent parasitism by exposed females (Consoli and others 1998). Potential effects on parasitism in the field were not examined in either case. In our study neither tebufenozide nor Btk had any effect on overall parasitism rates or parasitism by individual species (figs. 1 and 2). Niwa and others (1987) also found that *B. thuringiensis* had no effect on parasitism rates nor species distribution of parasitoids of the western spruce budworm, *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae). However, Hamel (1977) found increased larval parasitism of *C. occidentalis* by parasitoids attacking early instars and decreased parasitism by parasitoids attacking late instars and pupae. These latter results were attributed to the photonegative behavior of parasitized early instar larvae, which apparently allowed them to avoid contact with the insecticide. Tip moth larvae generally bore into a needle base immediately after eclosion, and virtually the entire immature period is spent within plant tissues (Berisford 1988). Little is known of the timing of attack by the various tip moth parasitoids. Because first instar larvae are targeted for insecticide treatment, only those attacking eggs or first instar larvae would be subject to indirect mortality due to death of the host. Those that attack later stages would suffer little indirect mortality.

These studies further illustrate that larval/pupal parasitism (40–50 percent) is an important source of tip moth mortality. Herbicide treatments did not affect parasitism rates, and infestation rates were highest in the untreated plots, suggesting that use of herbicides does not affect the ability of tip moth parasitoids to regulate moth populations. However, the fact that total parasitism was higher in the untreated plots raises the possibility that presence of greater amounts of vegetation can benefit tip moth parasitoids. Among the insecticides, the biologicals, Btk and tebufenozide, had little or no impact on tip moth parasitoids, but were less effective in controlling tip moth than acephate. This is important since parasitism could reduce residual tip moth populations when insecticidal control is incomplete. The negative effects of acephate appear to be species-specific, meaning that overall effects on tip moth parasitism could vary from region to region depending on variation in the species composition of the tip moth parasitoid complex. In generations or regions where *L. mediocris* is the dominant tip moth parasitoid, this insecticide would probably have relatively little effect on overall tip moth parasitism.

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