

EFFECTS OF VEGETATION CONTROL ON PARASITOIDS OF THE NANTUCKET PINE TIP MOTH, *RHYACIONIA FRUSTRANA* (LEPIDOPTERA: TORTRICIDAE)

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ABSTRACT

The Nantucket pine tip moth (*Rhyacionia frustrana* (Comstock)) is host to numerous parasitoid species that can cause substantial moth mortality. Little is known regarding the effects of forest management practices on these parasitoids. Abundance of parasitoids and parasitism rates, based on rearing of adult moths and parasitoids, were compared in herbicide-treated and untreated loblolly pine, *Pinus taeda* L., stands in the southeastern Georgia coastal plain. Three parasitoids, *Lixophaga mediocris* Aldrich, *Eurytoma pini* Bugbee, and *Hyssopus rhyacioniae* Gahan accounted for over 70% of total parasitism. Parasitism rates did not differ significantly between treated and untreated plots. Tip moth damage was higher in the untreated plots. Malaise trapping of parasitoids yielded no significant difference in numbers of tip moth parasitoids or total parasitoids captured in treated and untreated plots, suggesting a functional response of parasitoids to tip moth densities. Higher levels of naturally occurring vegetation did not improve tip moth control through increased parasitism rates.

Key Words: *Rhyacionia frustrana*, parasitoids, vegetation control, *Pinus taeda*, parasitism

RESUMEN

La polilla de pino Nantucket (*Rhyacionia frustrana* (Comstock)) es huésped a numerosas especies parasitoides que pueden causar mortalidad substancial de polilla. Poco se sabe en relación con los efectos de practicas de control forestal en estos parasitoides. La abundancia de parasitoides y las incidencias de parasitismo, basado en el cultivo de polillas adultas y parasitoides, fueron comparadas en áreas de pinos *Pinus taeda* L., sin tratar y tratados con herbicida, en el plano costero del sureste de Georgia. Tres parasitoides, *Lixophaga mediocris* Aldrich, *Eurytoma pini* Bugbee, y *Hyssopus rhyacioniae* Gahan resultaron en mas del 70% del parasitismo total. Incidencias de parasitismo no difirieron significativamente entre terrenos tratados y no tratados. Daño de polilla de pino fue mayor en los terrenos no tratados. Capturas de parasitoides no produjeron diferencias significativas en números de parasitoides de polilla o en el total de parasitoides capturados en terrenos tratados y no tratados, sugiriendo una respuesta funcional de parasitoides a densidades de polilla de pino. Niveles mas elevados de presencia de vegetación natural no mejoro el control de polilla de pino a través de cantidades más altas de parasitismo.

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a common insect pest of southern pines, attacking seedlings and saplings of loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Miller), and Virginia (*P. virginiana* Miller) pines (Berisford 1988). Eggs are laid on needles and shoots. Early instar larvae mine needles and fascicle sheaths. Later instars feed on the meristematic tissue of shoots and buds, causing shoot death and losses in form, wood quality and volume growth (Cade & Hedden 1987). The moth has 2 to 5 generations annually (depending on climatic conditions) and overwinters as a pupa inside of the dead shoot or bud (Berisford 1988).

Damage caused by the Nantucket pine tip moth is highly variable, and may be negligible or high enough to cause tree mortality. Increased tip

moth population fluctuations have been associated with intensive forest regeneration practices, including chemical control of competing vegetation to increase seedling growth and survival (Miller & Stephen 1983; Nowak & Berisford 2000). Tip moth populations may be constrained to some degree by natural agents, including parasitoids and predators (Eikenbary & Fox 1968a,b; Freeman & Berisford 1979; Wallis et al. 1980; Gargiullo & Berisford 1983; Warren 1985; McCravy & Berisford 1998, 2000). Approximately 60 species of parasitoids have been associated with the Nantucket pine tip moth (Yates & Beal 1962; Frank & Foltz 1997). However, potential effects of intensive forest management practices on tip moth parasitoids have received little attention. Herbaceous vegetation can be an important

source of food for adult parasitoids (Leius 1961, 1963; Syme 1975), and can also be important as refugia and in maintaining suitable microclimatic conditions (Reed et al. 1970; Powell 1986). Pimentel's enemy impact hypothesis (Pimentel 1961) suggests that natural enemies of herbivorous insects are more effective in diverse systems than in simple ones. In a review of tests of this hypothesis, however, Russell (1989) found the results to be inconclusive for parasitism.

We initiated a study to determine if chemical control of competing vegetation affects parasitism of the Nantucket pine tip moth. The objective of this study was to compare rates of parasitism and abundance of parasitoids of the tip moth in herbicide-treated and untreated loblolly pine stands.

MATERIALS AND METHODS

The study was conducted in 1996-97 at 2 one-year-old *P. taeda* plantations in Burke County, in the Georgia coastal plain. Site 1 was 70 ha and Site 2 was 47 ha. Tree density at each plantation was approx. 1500 trees/ha. In spring, 1996, each site was divided into 2 equally sized plots, with 1 randomly selected plot receiving treatment with the herbicides hexazinone (Velpar®, DuPont, Wilmington, DE) and sulfometuron methyl (Oust®, DuPont, Wilmington, DE) at rates of 2.34 and 0.22 liters/ha, respectively. The remaining halves were left as untreated plots. The treatment plots at each site were treated again in fall, 1996 with imazapyr (Arsenal®, American Cyanamid, Princeton, NJ) and glyphosate (Accord®, Monsanto, St. Louis, MO) at 0.58 and 2.38 liters/ha, respectively. All herbicides were applied by helicopter. There was no replication within sites. Rather, sites were treated as replicates to decrease the potential for confounding effects due to parasitoid immigration into small plots. In spring, 1996, 50 pines were randomly chosen in each plot of each study site to serve as permanent study trees. Tip moth infestations were evaluated on these trees by counting numbers of infested shoots 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 plot as well. Twenty randomly located 1 m² quadrats were sampled in each plot during each of the 4 tip moth generations. For each quadrat, a visual estimate of percentage ground cover was taken, and numbers of flowering plants were counted.

Collections of infested shoots for rearing of tip moths and parasitoids were made during the late larval/pupal stages of each tip moth generation. For summer (2nd), fall (3rd), and winter (4th) generations, 2,000 infested shoots were randomly collected from non-permanent study trees in each plot. Summer generation collections were done in early July and fall generation collections in mid-August, 1996. Collections of shoots for the over-

wintering generation were done in 2 stages. Half of the shoots were collected in late September, 1996 and half were collected in mid-January, 1997, in order to sample parasitoids that might emerge before the onset of winter as well as those emerging in late winter and early spring. Spring (1st) generation collections were done in early May, 1997. Because of low tip moth infestations in this generation, 1,000 shoots were collected from each plot. Shoots were returned to the laboratory and placed in ventilated rearing containers (Berisford et al. 1971), separated by site and treatment. Emerging adult moths and parasitoids were collected every 2-3 days. Moths and parasitoids were counted and parasitoids were identified to species using Yates' (1967) key, and placed in 70% 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 calculated based on relative numbers of emerged tip moth and parasitoid adults. Two parasitoids, *Hyssopus rhyacioniae* Gahan and *Pteromalus Swederus* sp., were determined to be gregarious based on dissection of individual tip moth-infested shoots, averaging 12.2 ± 1.20 (mean \pm SE, $n = 15$) and 2.92 ± 0.45 ($n = 12$) individuals per brood, respectively. Total numbers of individuals reared for these 2 species were divided by these means to provide a more accurate estimate of the number of parasitism events.

At site 1, parasitoids were collected using malaise traps to estimate the relative abundance of parasitoids in the herbicide-treated and untreated plots. Two traps, 1 in each treatment plot, were operated for 8, 5-day trapping periods bi-weekly from mid-June to early October 1996. Traps were randomly relocated for each trapping period. Insects were collected in 70% 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.

Mean percentage ground cover and mean number of flowering plants per plot were compared between treatments using paired t-tests. Two-way repeated measures analysis of variance, with generation as the repeated variable, was used to compare mean numbers of infested shoots per tree between treatments and sites, to compare overall parasitism rates between treatments and sites, and to analyze species-specific parasitism by the most common parasitoid species in relation to treatment. Percent parasitism data were arcsine transformed prior to analysis. Paired t-tests were used to compare numbers of parasitoids captured in malaise traps between treatments. It was noted

that larger parasitoids appeared to be relatively more common in samples from the untreated plots. Therefore, chi-square tests were used to analyze ratios of ichneumonoids and tachinids to microhymenoptera reared and captured in treated and untreated plots. All analyses were done using SigmaStat Version 2.0 software package (Jandel Scientific Software 1995).

RESULTS

The most common plant species found and months in which flowering individuals were present are shown in Table 1. Mean percent ground cover (\pm SE) was significantly greater in the untreated plots than in the treated plots ($t_{(7)} = 8.48$, $P < 0.001$), indicating that herbicide treatments were effective (Fig. 1). Mean number of flowering plants was also greatest in the untreated plots ($t_{(7)} = 2.82$, $P = 0.03$) (Fig. 1).

Tip moth infestation levels, based on numbers of damaged shoots per tree, were higher in the untreated plots than the treated plots (10.89 ± 1.41 vs. 2.64 ± 0.49 ; $F_{(1,3)} = 33.31$; $P = 0.01$). Infestation levels ranged from 7.96 ± 2.50 in the fall generation to 15.41 ± 4.15 in the winter for the untreated plots, and from 1.22 ± 0.18 in spring to 3.79 ± 0.21 in summer for the treated plots (Fig. 2). There was no significant difference between sites ($F_{(1,3)} = 1.26$, $P = 0.34$), and no significant interaction ($F_{(1,3)} = 1.04$, $P = 0.38$).

Overall, 7,198 parasitoids were reared, including 17 species in 9 families representing 2950 parasitism events. Three species, *Lixophaga mediocris* Aldrich, *Eurytoma pini* Bugbee, and *Hysosopus rhyacioniae* Gahan accounted for over 70% of total parasitism. Mean percent parasitism was 47.47 ± 7.94 in the treated plots and 46.65 ± 7.47 in the untreated plots ($F_{(1,3)} = 0.01$, $P = 0.92$). Difference in parasitism rates between sites was not significant ($F_{(1,3)} = 5.56$, $P = 0.10$), and there was no significant interaction ($F_{(1,3)} = 0.24$, $P = 0.66$). Parasitism was highest in spring (73.93 ± 2.94) and lowest in winter (22.36 ± 1.33).

There was no relationship between treatment and contribution to total parasitism among the 3 most common parasitoid species ($F_{(2,6)} = 0.06$, $P = 0.94$). However, as a group, ichneumonoids comprised a greater proportion of rearings, relative to microhymenoptera, in the untreated than the herbicide-treated plots at Site 1 (14.27% vs. 8.02%; $X^2_{(1)} = 13.53$, $P < 0.001$) and Site 2 (17.39% vs. 11.57%; $X^2_{(1)} = 8.57$, $P = 0.003$).

Malaise trapping resulted in 2,981 total parasitoid captures. Mean numbers of captures per trapping period (\pm SE) were 189.88 ± 49.15 in the herbicide-treated plot and 182.75 ± 36.90 in the untreated plot, and were not significantly different ($t_{(7)} = 0.11$, $P = 0.916$; Fig. 3). Ichneumonoids accounted for 9.09% of total captures and 11.77% of total parasitic hymenoptera, while microhymenoptera accounted for 68.13% and 88.23% of

TABLE 1. COMMON PLANT SPECIES FOUND IN QUADRAT SAMPLING AND MONTHS IN WHICH FLOWERING INDIVIDUALS WERE FOUND

Family and Species	Collection Date			
	Jun 96	Aug 96	Oct 96	Apr 97
Asteraceae				
<i>Eupatorium capillifolium</i> (Lamarck) Small			+	
<i>Gnaphalium obtusifolium</i> L.		+	+	
<i>Solidago</i> sp. L.				+
Caryophyllaceae				
<i>Cerastium glomeratum</i> Thuillier		+		
Cyperaceae				
<i>Cyperus retrorsus</i> Chapman		+		
Fabaceae				
<i>Stylosanthes biflora</i> Britton, Sterns, and Poggenburg	+	+		
<i>Tephrosia spicata</i> (Walter) Torrey and Gray		+		
Hypericaceae				
<i>Hypericum denticulatum</i> Humboldt, Bonpland, and Kunth		+		
Liliaceae				
<i>Smilax</i> sp. L.	+			
Passifloraceae				
<i>Passiflora incarnata</i> L.	+			
Vitaceae				
<i>Vitis rotundifolia</i> Michaux	+			

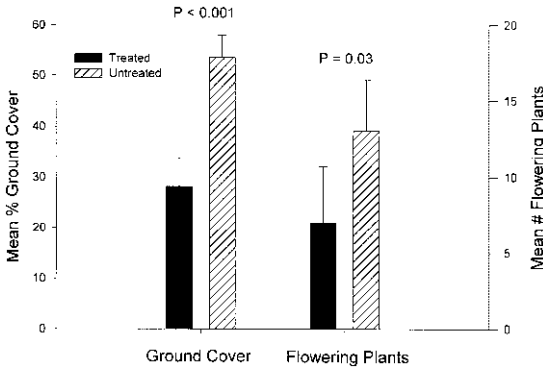


Fig. 1. Mean percentage ground cover (±SE) and mean number of flowering plants (±SE) per 1 m² quadrat in herbicide-treated and untreated plots. Observations were averages of 20 quadrats for each study site and tip moth generation (n = 8, each mean).

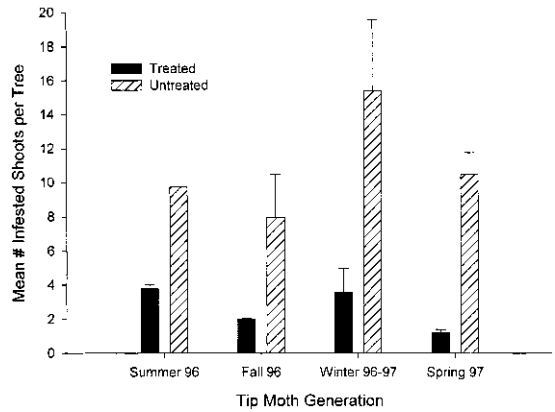


Fig. 3. Mean numbers of parasitoids captured (±SE) in malaise traps per 5-day trapping period in herbicide-treated and untreated plots. Between-plot differences were non-significant (P > 0.20, each comparison).

these totals, respectively. Tachinids comprised 22.78% of total captures. There were no significant between-treatment differences in captures of ichneumonoids ($t_{(7)} = 1.037$, $P = 0.334$), microhymenoptera ($t_{(7)} = 0.409$, $P = 0.695$), or tachinids ($t_{(7)} = 0.328$, $P = 0.753$). However, there was a significantly greater proportion of ichneumonoids and tachinids captured, relative to microhymenoptera, in the untreated (35.29%) than the treated (28.57%) plot ($X^2_{(1)} = 15.199$, $P < 0.001$). A total of 136 known tip moth parasitoids were captured. Mean numbers captured/trap period (±SE) were 9.50 ± 2.84 in the herbicide-treated plots and 7.50 ± 1.84 in the untreated plots ($t_{(7)} = 0.528$, $P = 0.613$). *Lixophaga mediocris* (72% of total) and *E. pini* (14% of total) were the most common species captured.

DISCUSSION

Most studies of tip moth damage in relation to forest regeneration practices have found an inverse relationship between damage and amount of competing vegetation (Berisford & Kulman 1967; White et al. 1984; Hood et al. 1988; Ross et al. 1990). However, Miller & Stephen (1983) and Nowak & Berisford (2000) found no differences in damage levels between herbicide-treated and untreated plots, but greater temporal variation in tip moth damage levels in the treated plots. We also found greater temporal variation in damage levels in treated plots, at least on a relative scale, with a roughly 3-fold difference between peak and lowest infestation rates in the treated plots, but only a 2-fold difference in the untreated plots (Fig. 2). Nowak & Berisford (2000) also found that infestation levels were generally lower in treated than untreated plots at low tip moth densities, as was the case in our study. There was little difference in variation in parasitism rates between treatments in our study, suggesting that the greater relative fluctuations in tip moth damage in the treated plots, and greater overall damage in the untreated plots, were not due to disruption of parasitoid populations.

The overall tip moth parasitism rate of 47% generally agrees with that of 42% found by Freeman & Berisford (1979) in the Georgia piedmont and 41% found by Eikenbary & Fox (1965) in the South Carolina coastal plain, but is higher than the 26% rate obtained by the latter authors in the South Carolina piedmont. Tip moth parasitism rates were highest in the spring generation and lowest in the winter in our study. Gargiullo & Berisford (1983) found a similar pattern for tip moth parasitism in the Georgia piedmont. If tip moth parasitoids attack specific life stages, the

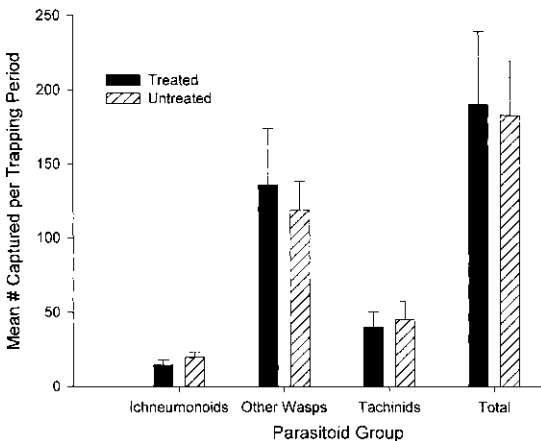


Fig. 2. Mean numbers of infested shoots per tree (±SE) in herbicide-treated and untreated plots for 4 tip moth generations (P = 0.004, all generations).

increased asynchrony of tip moth development in later generations (Fettig et al. 2000) could make it more difficult for the parasitoids to find suitable hosts, since fewer tip moths in the required life stage(s) would be present at any given time.

Tip moth populations were approx. 2 to 5 times higher in the untreated plots, based on damage estimates, but there was no difference in parasitism rates between treatments, meaning that greater total parasitism 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 perhaps resulting from greater parasitoid fecundity or longevity, or less searching time due to higher host densities. The ratio of ichneumonoids and tachinids to microhymenoptera reared and captured in malaise traps was greatest in the untreated plots, suggesting that vegetation control in pine plantations may have a relatively greater impact on populations of the larger parasitoids. Larger-bodied parasitoids may have greater metabolic requirements, which could affect the amount and type of food needed. Small wasps are also probably more affected by wind currents that result from lack of vegetation to act as a windbreak. There is also evidence that some female ichneumonoids must feed at flowers to complete egg development (van Emden 1963). Numerous studies (Syme 1975; Foster & Ruesink 1984; Wäckers & Swaans 1993; Idris & Grafius 1995, 1996, 1997; Johanowicz & Mitchell 2000) have documented the importance of flower availability on fecundity, survival, and parasitism rates by ichneumonoids. Detailed studies of specific plant associations of tip moth parasitoids, and effects of vegetation control practices on these plants, are needed.

In summary, we found that total tip moth parasitism was greater in untreated than in herbicide-treated plots, but parasitism rates were equal between plots. Tip moth damage was substantially higher in untreated than in herbicide-treated stands, suggesting that vegetation management practices do not necessarily affect the role of parasitoids in tip moth population control.

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