# Parasitoids of the Nantucket Pine Tip Moth (Lepidoptera: Tortricidae) in the Coastal Plain of Georgia[1]

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**Abstract** Parasitism of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), was studied for four consecutive generations in the Georgia coastal plain by collecting tip moth-infested shoots and rearing adult moths and parasitoids. Nineteen species of parasitoids were collected. Based on numbers of emerging adults, the overall tip moth parasitism rate was 44.8%. *Lixophaga mediocris* Aldrich, *Eurytoma pini* Bugbee, and *Hyssopus rhyacioniae* Gahan were the most abundant parasitoids, accounting for 36.3%, 25.4%, and 11.7% of parasitism, respectively. Parasitism was highest in the summer, 1996, and spring, 1997, generations, and lowest in the 1996-97 overwintering generation. Emergence curves of *L. mediocris* and *Hy. rhyacioniae* overlapped that of *R. frustrana* considerably. Examination of unemerged tip moth pupae and parasitoid puparia indicated that *E. pini* was predominately hyperparasitic. The parasitoid complex in the coastal plain was different from that in the Georgia Piedmont Plateau and from other published reports of tip moth natural enemies.

**Key Words** Nantucket pine tip moth, *Rhyacionia frustrana,* parasitoids, parasitism

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is an important pest of southern pine seedlings and saplings. Larvae mine needles, shoots and buds, killing the shoots and often causing tree deformation and loss of growth (Berisford 1988). The moth overwinters in the pupal stage inside shoots and buds and has four generations annually in the Georgia coastal plain (Gargiullo et al. 1985). The Nantucket pine tip moth has a rich complement of parasitoids, some of which may be important mortality agents (Berisford 1988). However, the parasitoid complex of the Nantucket pine tip moth in the commercially important southeastern coastal plain has not been intensively investigated. In this study we examined the species composition and relative abundance of the Nantucket pine tip moth parasitoid complex in the Georgia coastal plain.

## Materials and Methods

A total of 40,000 loblolly pine (*Pinus taeda* L.) shoots which had been killed by tip moth attacks were randomly collected from three plantations in the Georgia coastal plain, two in Burke Co., near Waynesboro, and one in Bulloch Co., near Statesboro. Four thousand shoots were collected at each site for the summer 1996, late summer 1996, and overwintering 1996-97 generations, and 2,000 shoots were collected at

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each Waynesboro site for the spring 1997 generation. Shoots were placed in ventilated rearing cans (Berisford et al. 1971), and emerging adult moths and parasitoids were collected, counted, and parasitoids tentatively identified to species. When emergence for each generation had ended, shoots were removed from the rearing cans, dissected, and examined for unemerged tip moth pupae and parasitoid pupae or puparia, as well as any adult tip moths and parasitoids that had emerged but failed to reach the collection jar. Unemerged pupae and puparia were dissected and examined for the presence of a tip moth, parasitoid(s), or cocoon. Series of each presumed parasitoid species were sent to the U.S. National Museum (Beltsville, MD) or the Center for Insect Identification (Cincinnati, OH) for positive identification. Tip moth infestation rates were estimated by counting numbers of infested shoots on 100 randomly chosen pine trees at each site for each generation (excluding spring 1997 at the Statesboro site). Abundance and emergence patterns of parasitoid species were determined and compared within and between generations. Differences in overall parasitism rates among sites and generations were analyzed using contingency table analysis with the $G$-test of independence (Sokal and Rohlf 1995). Statistical analyses were done using Statview 512+ (Abacus Concepts 1986). Voucher specimens were deposited in the Entomology Collections, Museum of Natural History, University of Georgia, Athens, GA 30602.

## Results and Discussion

A total of 9,629 parasitoids were reared, representing two orders, nine families, and 19 species. *Hyssopus rhyacioniae* Gahan (Hymenoptera: Eulophidae) and *Pteromalus* Swederus sp. (Hymenoptera: Pteromalidae) were found to be gregarious parasitoids based on dissection of individual tip moth-infested shoots, averaging 12.2 ± 1.20 (mean ± SE, N = 15) and 2.92 ± 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 actual tip moth parasitism attributable to them. Based on relative numbers of emerging adults, overall tip moth parasitism was 44.8% (Table 1). This is similar to the rates of 42% found in the Georgia piedmont (Freeman and Berisford 1979) and 41% in the South Carolina coastal plain (Eikenbary and Fox 1965), but is higher than the 26% obtained by the latter authors in the South Carolina piedmont. Parasitism rates were significantly different among generations ($G$ = 1465.78, df = 3, $P$ = 0.0001) with highest parasitism in the spring (73.6%) and summer (67.0%) generations and lowest in the late summer (38.8%) and overwintering (27.3%) generations. Much of the high parasitism occurring in the spring generation was due to *Lixophaga mediocris* Aldrich (Diptera: Tachinidae), which accounted for almost two-thirds of parasitoids reared (Table 1). The decline in parasitism late in the year could be a result of the less synchronized tip moth life cycle that occurs at that time. Parasitoids that attack a particular life stage would find relatively fewer suitable hosts under such conditions. Eikenbary (1964) found that *L. mediocris* emergence was highly synchronized with tip moth emergence in South Carolina, and that parasitism by this tachinid decreased greatly in the last generation. Long-term studies are needed to determine if this pattern is consistent from year to year. *Lixophaga mediocris, Eurytoma pini* Bugbee (Hymenoptera: Eurytomidae), and *Hy. rhyacioniae* were the most abundant parasitoids found in this study, accounting for 73.4% of total parasitoids (Table 1). Among the Hymenoptera, chalcidoids were most abundant, representing 80.4% of rearings in this order. With regard to seasonal

**Table 1. Numbers of parasitoids reared from pine shoots infested with *Rhyacionia frustrana* (all locations pooled). Dates are for four tip moth generations. Numbers in parentheses are percentages of total parasitoids.**

| | Summer 1996 | Late Summer 1996 | Overwintering 1996-97 | Spring 1997* | Totals |
|---|---|---|---|---|---|
| DIPTERA | | | | | |
| Tachinidae | | | | | |
| *Lixophaga mediocris* | 128 (16.0) | 116 (14.4) | 338 (30.7) | 924 (64.3) | 1506 (36.3) |
| HYMENOPTERA | | | | | |
| Chalcididae | | | | | |
| *Conura side* | 21 (2.6) | 14 (1.7) | 2 (0.2) | 13 (0.9) | 50 (1.2) |
| *Haltichella rhyacioniae* | 37 (4.6) | 13 (1.6) | 30 (2.7) | 109 (7.6) | 189 (4.6) |
| Eulophidae | | | | | |
| *Aprostocetus marylandensis* | 1 (0.1) | 45 (5.6) | 47 (4.3) | 0 (0.0) | 93 (2.2) |
| *Euderus subopacus* | 0 (0.0) | 1 (0.1) | 7 (0.6) | 4 (0.3) | 12 (0.3) |
| *Hyssopus rhyacioniae*** | 66 (8.3) | 172 (21.3) | 219 (19.9) | 28 (1.9) | 485 (11.7) |
| *Paraolinx taedae* | 1 (0.1) | 43 (5.3) | 0 (0.0) | 0 (0.0) | 44 (1.1) |
| *Sympiesis* sp. | 1 (0.1) | 0 (0.0) | 2 (0.2) | 2 (0.1) | 5 (0.1) |
| Eupelmidae | | | | | |
| *Eupelmus cyaniceps* | 23 (2.9) | 10 (1.2) | 38 (3.5) | 83 (5.8) | 154 (3.7) |
| *Eupelmus* sp. | 1 (0.1) | 0 (0.0) | 2 (0.2) | 2 (0.1) | 5 (0.1) |
| Eurytomidae | | | | | |
| *Eurytoma pini* | 456 (57.1) | 306 (38.0) | 156 (14.2) | 136 (9.5) | 1054 (25.4) |
| Pteromalidae | | | | | |
| *Pteromalus* sp.† | 0 (0.0) | 0 (0.0) | 28 (2.5) | 3 (0.2) | 31 (0.7) |
| Braconidae | | | | | |
| *Agathis acrobasidis* | 5 (0.6) | 1 (0.1) | 42 (3.8) | 3 (0.2) | 51 (1.2) |
| *Bracon* sp. | 25 (3.1) | 1 (0.1) | 13 (1.2) | 18 (1.3) | 57 (1.4) |
| *Macrocentrus ancylivorus* | 28 (3.5) | 75 (9.3) | 107 (9.7) | 55 (3.8) | 265 (6.4) |
| Ichneumonidae | | | | | |
| *Exeristes comstockii* | 0 (0.0) | 0 (0.0) | 10 (0.9) | 10 (0.7) | 20 (0.5) |
| *Itoplectis conquisitor* | 0 (0.0) | 0 (0.0) | 31 (2.8) | 6 (0.4) | 37 (0.9) |
| *Temelucha rhyacioniae* | 1 (0.1) | 0 (0.0) | 0 (0.0) | 28 (1.9) | 29 (0.7) |
| Bethylidae | | | | | |
| *Goniozus electus* | 5 (0.6) | 9 (1.1) | 29 (2.6) | 14 (1.0) | 57 (1.4) |
| Total Parasitoids | 799 | 806 | 1101 | 1438 | 4144 |
| % Tip Moth Parasitism | 67.0 | 38.8 | 27.3 | 73.6 | 44.8 |

* Waynesboro sites only.

**Numbers represent total individuals reared divided by mean brood size of 12.2.

† Numbers represent total individuals reared divided by mean brood size of 2.92.

patterns of parasitism, *L. mediocris* was by far the most abundant in the spring generation, and relatively scarce in summer and late summer. *Hyssopus rhyacioniae* was most abundant in the late summer and overwintering generations, while *E. pini* was most abundant in the summer and late summer generations.

*Lixophaga mediocris,* the most abundant parasitoid in this study, was also found to be important in the Georgia piedmont, accounting for 45.2% of parasitoids reared. However, *Hy. rhyacioniae,* the third most abundant parasitoid found in our study, was virtually absent in that region (Freeman and Berisford 1979). This species is also more abundant in the coastal plain than the piedmont of South Carolina (Eikenbary and Fox 1965). *Campoplex frustranae* Cushman (Hymenoptera: Ichneumonidae), a component of tip moth parasitoid surveys in many regions, including the Georgia piedmont (Frreman and Berisford 1979, Gargiullo and Berisford 1983), was not found in our collections. It may be that this parasitoid reaches its distributional limit in the Georgia coastal plain, perhaps due to climatic constraints, or because of a lack of ability to synchronize with the four generation tip moth life cycle, which begins to occur at the Georgia fall line (Berisford et al. 1992). The number of generations of this parasitoid appears to be governed by the number of generations of its tip moth hosts (Dowden 1962, Schaffner 1959). *Campoplex frustranae* was also absent from parasitoid surveys in Florida (McGraw et al. 1974), where four or more tip moth generations are common. This parasitoid was much less abundant in the coastal plain (accounting for 23.4% of parasitism, averaged over 2 yrs) than in the piedmont (41.7% of parasitism) in the South Carolina study of Eikenbury and Fox (1965). Intensive surveys along the piedmont/coastal plain transition zone are needed to determine the distributional limits of this important tip moth parasitoid.

Mean tip moth infestation rates were highest at the Waynesboro II site, overwintering generation, and lowest at the Waynesboro I site, late summer generation (Table 2). Otherwise, infestation rates were between five and eight infested shoots per tree. There was no significant correlation between tip moth parasitism rate and infestation rate, analyzed across site and generation ($n = 11$; $r = -0.26$, $P = 0.433$).

Relative emergence patterns of tip moths and the three most abundant species of parasitoids are shown in Fig. 1. These data are for the spring generation, both Waynesboro sites combined. There was much overlap between tip moth adult emergence and emergence of *L. mediocris,* and, to a lesser extent, *Hy. rhyacioniae.* These results agree with those of Eikenbary (1964), who found that most tip moth parasitoids, including *L. mediocris* and *Hyssopus* sp., emerge at about the same time as adult moths. Current insecticide control measures involve targeting first-instar tip

**Table 2. Mean numbers (± SE) of infested shoots per tree at three study sites for four tip moth generations. N = 100 trees for each mean.**

| Generation | Statesboro | Waynesboro I | Waynesboro II |
|---|---|---|---|
| Summer 1996 | 7.73 ± 0.47 | 6.84 ± 0.47 | 6.67 ± 0.52 |
| Late Summer 1996 | 5.80 ± 0.59 | 3.73 ± 0.29 | 6.20 ± 0.58 |
| Overwintering 1996-97 | 6.14 ± 0.59 | 6.73 ± 0.63 | 12.26 ± 1.13 |
| Spring 1997 | | 6.40 ± 0.70 | 5.29 ± 0.56 |

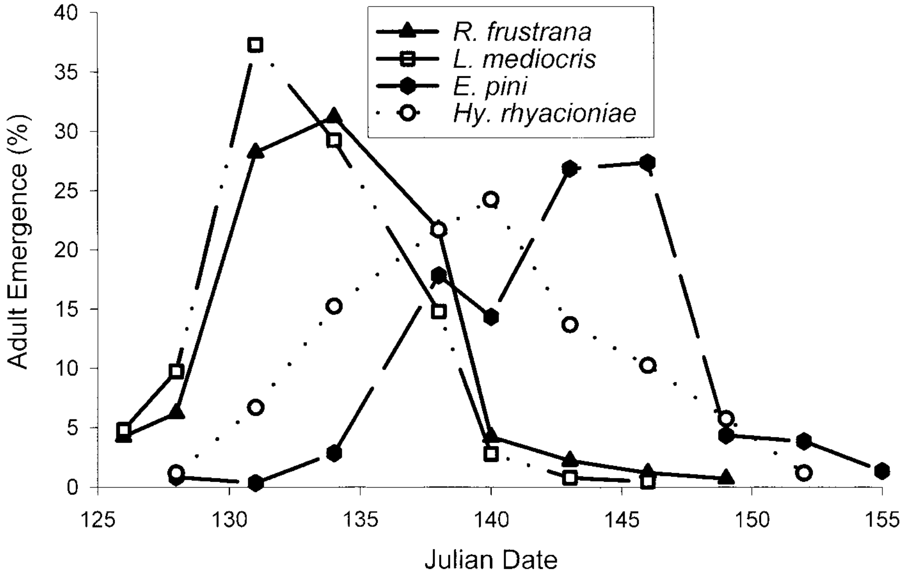


Fig. 1. Emergence patterns of *R. frustrana* and three species of parasitoids for the spring 1997 generation. Julian date 125 = 5 May.

moth larvae using a spray timing model (Fettig et al. 1998, Gargiullo et al. 1985). It therefore appears likely that current insecticide control practices have adverse effects on parasitoid adults. In our study, there was some separation between tip moth adult emergence and emergence of *E. pini,* suggesting that this parasitoid would be less affected by chemical control. However, due to its primarily hyperparasitic habits, *E. pini* probably does not contribute as much to tip moth population regulation as its abundance would suggest.

Unemerged adults of five species of parasitoids were found during dissections of tip moth pupae and puparia of *L. mediocris* and *Macrocentrus ancylivorus* Rohwer (Hymenoptera: Braconidae) (Table 3). For the five species combined, hyperparasitism was found to have occurred in two-thirds (38 of 57) of parasitism events. Of these five species, only *E. pini* was a substantial part of the tip moth parasitoid fauna (Table 1). Cushman (1927) considered this species to be mainly a primary parasitoid, but Arthur (1961) found it to be cleptoparasitic on *R. buoliana* (Schiffermüller). All ten *E. pini* recovered directly from hosts in our study were hyperparasitic (four from *L. mediocris,* six from *M. ancylivorus*), as were three of five *E. pini* reared directly from hosts (two from *L. mediocris,* one from *C. frustranae*) by Freeman and Berisford (1979). The inverse relationship between abundances of *E. pini* and *L. mediocris* in our study (Table 1) raises the possibility that *E. pini* has detrimental effects on *L. mediocris* populations. *Lixophaga mediocris* emerges from fifth-instar tip moth larvae, earlier than most other tip moth parasitoids (Freeman and Berisford 1979). It is possible that this earlier development could allow *L. mediocris* to outcompete other tip moth parasitoids when *E. pini* populations are at low levels, but at high populations *E. pini* reduces *L. mediocris* numbers, allowing other species to increase. Such hyper-

**Table 3. Parasitic habits of some hyperparasitoids recovered from tip moth pupae and parasitoid puparia.**

| Parasitoid | Recovered from *R. frustrana* | *L. mediocris* | *M. ancylivorus* | % Hyperparasitism |
|---|---|---|---|---|
| *Pteromalus* sp. | 8 | 2 | 2 | 33.3 |
| *C. side* | 7 | 11 | 1 | 63.2 |
| *E. cyaniceps* | 0 | 1 | 1 | 100.0 |
| *E. pini* | 0 | 4 | 6 | 100.0 |
| *Ha. rhyacioniae* | 4 | 6 | 4 | 71.4 |
| Totals | 19 | 24 | 14 | 66.7 |

parasitoid-mediated competition has been found among parasitoids of the gall midge, *Rhopalomyia californica* Felt (Diptera: Cecidomyiidae) (Force 1970, 1974). *Eurytoma pini* is one of the most abundant and ubiquitous of tip moth parasitoids in North America (Warren 1985). Detailed studies of the biology of *E. pini* are needed to clarify its impact on populations of tip moths and other tip moth parasitoids.

In this study, we found substantial tip moth parasitism occurring in the Georgia coastal plain. Three parasitoids were responsible for most of the parasitism—*L. mediocris, E. pini,* and *Hy. rhyacioniae*—and one, *C. frustranae,* was conspicuous in its absence. Future studies will be needed to determine the factors that influence the distribution and abundance of these parasitoids and their roles in tip moth population regulation.

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