Control of Low-Level Nantucket Pine Tip Moth Populations: A Cost-Benefit Analysis

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ABSTRACT: *The Nantucket pine tip moth,* Rhyacionia frustrana, *an important pest of intensively managed loblolly pine, can cause significant long-term volume loss in plantations. The primary objective of this study was to establish an economic damage threshold beyond which chemical control of this pest becomes cost-effective. Tip moth damage estimates were obtained from 200 trees for each generation over a 3-year period after planting on two sites in the Georgia Piedmont. A volume index (D^2H) was obtained for each of these trees at the end of the study. Significant reductions in volume were observed among trees with relatively low damage levels (10–30% of shoots infested on average over a 3-year period) compared with those trees sprayed with insecticide throughout the study. Growth projection models were used to extrapolate 3-year volume differences among treatments to a full rotation. These and other parameters were used to calculate land expectation values and, subsequently, willingness to pay values for tip moth control at the beginning of the rotation using various discount rates. The results of this analysis suggest that an economic injury level for R. frustrana may be reached when damage levels, on average, exceed 30% infested shoots. South. J. Appl. For. 30(4):182–187.*

Key Words: *Rhyacionia frustrana, Pinus taeda*, damage threshold, chemical control.

Loblolly pine (*Pinus taeda* L.) is the most commercially important tree species in the southeastern United States, where it covers approximately 16 million ha, over one-half of which consists of plantations (South and Buckner 2003). The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), has the greatest impact of any insect pest on annual growth of loblolly pine seedlings and saplings throughout its range (Berisford 1988, Asaro et al. 2003), particularly in intensively managed plantations (Nowak and Berisford 2000). *R. frustrana* has two to five generations per year, with three to four generations predominating in most areas (Fettig et al. 2000a). Female moths oviposit on needles, shoots, and buds. After eclosion, first-instar larvae mine needles. Later, instars bore into and feed within the shoots, where pupation and overwintering occur (Yates et al. 1981).

The negative impact of the Nantucket pine tip moth on growth and yield of loblolly pine has been well documented (Lashomb et al. 1978, Young et al. 1979, Cade and Hedden 1987, Berisford et al. 1989, Fettig et al. 2000b, Nowak and Berisford 2000). However, earlier studies have downplayed the effect of the tip moth on long-term growth (Warren 1964, 1968, Beal 1967, Merrifield et al. 1967, Warren and Young 1972, Shepard 1973, Williston and Barras 1977). These earlier studies have been criticized for the following reasons: (1) tip moth density or damage was not quantified on treated or untreated plots, making correlations with growth loss impossible; (2) chemical control was applied over long periods, which is both impractical and uneconomical; and (3) comparisons among sites with variable stocking densities, plot sizes, and thinning intervals made long-term growth responses difficult to interpret (Young et al. 1979, Stephen et al. 1982, Stephen 1983, Cade and Hedden 1987, Asaro et al. 2003).

Despite evidence that *R. frustrana* can cause significant, long-term growth losses in managed loblolly pine plantations, there is currently no economic injury level identified

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above which the application of insecticides would be warranted. This lack of knowledge has inhibited the use of chemical control against this pest, the cost of which may exceed marginal increases in productivity (Cade and Hedden 1987, Cameron 1996). The application of economic thresholds to forestry problems has been limited, because of, in part, much longer production cycles than those in agriculture (Fox et al. 1997). In addition, establishing an economic threshold for *R. frustrana* has been particularly daunting because of the multiple and variable number of generations throughout its range (two to five) and the considerable variation in site characteristics, growth rate, and management intensity of loblolly pine throughout the southeastern United States.

The economic injury level (EIL) concept was first proposed by Stern et al. (1959) and was designed initially to encourage more rational use of pesticides (Pedigo 1989). It is defined as the amount of injury that will justify the cost of artificial control measures. Action or damage thresholds indicate when management actions should commence (Pedigo et al. 1986, Pedigo 1989). Action thresholds are set most often slightly lower than the EIL to reduce the chance of economic loss occurring. Such thresholds are useful for prioritizing areas where control techniques are warranted (Saunders et al. 1985, Coulson et al. 1988, MacLean and Porter 2001). Although determination of the EIL has been difficult for most pests because of the great number of biological and economic parameters involved (Poston et al. 1983, Onstad 1987, Skold et al. 1995), many have attempted to establish damage thresholds for various pests as a first step toward integrated pest management (IPM) (Burts 1988, Stewart and Sears 1988, Kabissa 1989, Ezulike and Egwuata 1990, Theunissen and Schelling 1997).

An IPM system is feasible for *R. frustrana* given the amount of research that has been devoted to this pest and its importance to intensive forestry. Furthermore, there are many similarities between intensive forestry and agricultural systems during that portion of the rotation for which tip moths are a problem (i.e., mechanical site preparation; machine planting; genetically improved seedlings; and the application of fertilizer, herbicides, and insecticides; Nowak and Berisford [2000] and Asaro et al. [2003]). Our objectives were to estimate a damage threshold for the Nantucket pine tip moth by quantifying damage during each generation over three growing seasons and over a range of damage levels, determine short-term per tree and per stand volume reductions caused by varying degrees of tip moth attack over a 3-year period, project future growth and monetary losses based on these damage estimates, and provide a cost-benefit analysis for tip moth chemical control.

Materials and Methods

Study Location and Design

Two sites in northeast Oglethorpe County, Georgia (site 1, 33°57′ N and 82°54′ W; site 2, 33°58′ N and 82°55′ W) were established in April 1998 in recently planted loblolly pine plantations. There are three annual generations of the Nantucket pine tip moth in this region (Fettig et al. 2000a). The plantations were established on sites formerly growing loblolly pine for pulpwood production and harvested during the previous year. The sites were burned, harrowed, and planted with one to zero seedlings at 1,750 trees/ha in February 1998. Site 1 soils were characterized by a mixture of a Cecil sandy loam (2–6% slopes, very deep, well drained, clay subsoil extending to a depth greater than 40 in., moderate permeability, and available water capacity) and a Cecil sandy clay loam (same characteristics as Cecil sandy loam except for 6–10% slopes, eroded). Site 2 soils were characterized by a mixture of a Pacolet sandy clay loam (10–25% slopes, eroded, very deep, well drained, clay subsoil extending to a depth of 18–40 in., moderate permeability, and available water capacity) and a Cecil sandy clay loam. Site indices for loblolly pine at a base age of 25 years were estimated to be 60 (±5) based on growth of adjacent stands planted in the mid-1970s. To control competing vegetation, herbicides were applied after planting using sulfometuron methyl (Oust, 0.56 kg active ingredient [AI]/ha) and imazapyr (Chopper, 0.56 kg AI/ha), with an application during the following spring of Chopper (1.4 kg AI/ha) and metsulfuron methyl (Escort 0.05 kg AI/ha).

On each site, a plot of 200 trees was established in a completely randomized design to maximize degrees of freedom for error; this is particularly important because the study is designed to compare trees in different damage categories, and some of these categories may include very few sample trees. Blocking would further reduce the degrees of freedom for comparison of multiple damage categories.

Trees selected for treatment and measurement were positioned 10 per row, every other tree, and every other row. This allowed for adequate spacing between treatments and broad coverage of the plantation. Within these plots were the following randomly assigned treatments: 150 trees were unsprayed and 50 trees received chemical control. Chemical tip moth control was applied with a backpack sprayer using permethrin (Pounce 3.2 EC [emulsifiable concentrate]; FMC, Philadelphia, PA) three times each year at a rate of 0.6 ml of formulated product per liter of water. Timing of control was based on the accumulation of degree-days (°C) using a biophenometer (Model T 151; Dataloggers, Logan, UT; Gargiullo et al. [1985], Fettig and Berisford [1999a]). Degree-day accumulations were based on developmental temperature thresholds for *R. frustrana* of 9.5° C (lower) and 33.5° C (upper; Haugen and Stephen [1984]). The purpose of the control treatment was not only to directly compare sprayed and unsprayed tree volumes, but also to insure some trees had little or no damage in case natural damage levels were exceptionally high. A broad range of damage levels among trees is necessary to identify a damage threshold with reasonable accuracy.

Damage per tree was determined at the conclusion of each tip moth generation. Percent shoot damage for each tree was obtained by counting all infested and uninfested shoots on the tree (one shoot is defined as being at least 2.5 cm long and terminating in a bud). Chemical control was applied three times each year for 3 years (1998–2000). Tree heights and basal diameters were measured at the end of the 3rd year of the study after cessation of growth. These were converted into a tree stem volume index by multiplying the square of the diameter by the total height (D^2H). This volume index correlates well with aboveground biomass (Tiarks and Haywood 1981, Hatchell et al. 1985).

Data Analysis

All sprayed and unsprayed trees from both sites were clustered into separate damage categories (intervals of 10%) based on the average whole tree percentage of infested shoots during the 3-year study period (nine tip moth generations). Average tree volume within each damage category and tip moth generation were compared using analysis of variance (ANOVA) followed by Tukey's test for multiple comparison of means or Kruskal-Wallis ANOVA on ranks and Dunn's test if normality and equal variance assumptions were not met (SigmaStat 3.1, 2004, Systat Software, Inc., Point Richmond, CA). Significance levels for all tests were set at $\alpha = 0.05$.

Cost-Benefit Analysis

The maximum willingness to pay for tip moth treatment at the beginning of a rotation is the difference between the profitability of timber production with treatment and the profitability of timber production without treatment. This value can be calculated for varying levels of tip moth damage. The profitability of timber production starting with bare land can be calculated for even-aged stands using the so-called Faustmann formula or, equivalently, land expectation value (LEV), which can be expressed as

$$\mathrm{LEV} = \frac{p_p v(t)_p + p_{cns} v(t)_{cns} + p_s v(t)_s) e^{-rt} - C}{\mathbf{1} - e^{-rt}} - \frac{a}{r},$$

where p_p, $v(t)_p$, p_{cns}, $v(t)_{cns}$, and p_s, $v(t)_s$ are prices and volumes (at time t) of pine pulpwood, chip-n-saw, and sawtimber, respectively. The C is the combined site preparation and planting costs at the beginning of the rotation, a is the annual property tax, and r is the real discount rate. LEV then is the value that can be paid for bare land that is used to grow successive, identical timber crops into perpetuity and still earn an r real rate of return. Because calculated LEVs will likely be higher for cases where tip moth control is used at different levels of damage, the total value of control (TVC) over an infinite time horizon as given by change in LEV can be calculated as

$$\mathrm{TVC} = \mathrm{LEV}_{\mathrm{w/}} - \mathrm{LEV}_{\mathrm{w/o}}$$

where $\mathrm{LEV}_{\mathrm{w/}}$ and $\mathrm{LEV}_{\mathrm{w/o}}$ are LEVs with and without tip moth control, respectively. The willingness to pay (WTP) for control over one rotation, however, is somewhat less and is given by

$$\mathrm{WTP} = \mathrm{TVC}(1 - e^{-rt^*}),$$

where t^* is the optimal rotation age with control.

We used a loblolly pine growth model (Pienaar and Rheney 1997) to calculate future volumes ($v(t)$). The model has previously been used in economic analyses by Borders and Bailey (2001) and Yin and Sedjo (2001). This model is based on empirical data collected from intensively managed, even-aged, unthinned loblolly pine plantations in the Piedmont and Upper Coastal Plain regions of the southeastern United States. This model predicts various measures of timber production such as basal area and volumes of sawtimber, chip-n-saw and pulpwood, as a function of stand age, tree density, and site index.

To calculate bare land values from timber production, we assumed that timber prices were \$7, 26, and 43/m^3 for pulpwood, chip-n-saw, and sawtimber, respectively. These values are recent prices averaged over the previous year and are taken from *Timber Mart-South* (Norris Foundation 2004). Site preparation and planting costs (including herbicide costs) were assumed to be \$583/ha and fertilization costs were assumed to be \$136/ha (Dubois et al. 2003). These costs assumptions however, although impacting overall profitability levels (i.e., LEV), do not influence WTP estimates for tip moth control because they affect equally both with and without treatment cases. Annual property taxes were set at \$10/ha per year. We calculated TVC and WTP at three different real discount rates of 3, 5, and 7%. There is no hard and fast rule on what discount rate to use in discounted cash flow analysis, but this range of rates is not uncommon. The applicable rate will depend on the landowner's required real rate of return and aversion to risk.

The methodology used to simulate future timber volumes of stands with tip moth damage are as follows: we assumed that average percent tip moth damage during the first 3 years of plantation establishment would impact volume growth at the same rate until the age of 12 years, at which time volume in stands with damage would begin to converge to volumes in stands without damage. This assumption is conservative, however, because some studies have shown no convergence of volume by the age of 12 years between protected and unprotected stands (Cade and Hedden 1987) or even divergence by the age of 12 years (Cade and Hedden 1987) up to the age of 18 years (C.W. Berisford, unpublished data, 2002). The optimal rotation age was determined by maximizing the LEV formula with respect to time t.

Results and Discussion

Growth Differences

Due in part to drought conditions, seedling mortality between 10 and 20% occurred at each site and reduced the number of trees available for analysis. In general, per tree damage was very low throughout the study; at sites 1 and 2, average percentage of shoots infested did not exceed 30 and 42% for any tree, respectively, and a majority of trees averaged between 0 and 20% damage at both sites. Site 1 was the more productive of the two sites, with an average of 65.5% greater volume among sprayed trees. There were no volume differences among sprayed trees and unsprayed trees in the 0–10% average damage category ($P > 0.05$; Table 1). However, trees in the 10–20% damage category averaged 28.4 and 16.5% less volume than sprayed trees at sites 1 and 2, respectively, although there were no

Table 1. Average (±SE) loblolly pine volume by treatment and Nantucket pine tip moth damage category and percent change in volume of damaged trees relative to sprayed trees after three growing seasons.

Damage category	Site 1 average volume (cm^3)	Site 1% change volume (3-yr)	Site 2 average volume (cm^3)	Site 2% change volume (3-yr)
Spray 0–5% Damage	4,163 (500) a* n = 42	0%	2,515 (166) a n = 49	0%
No spray 0–10% Damage	4,245 (601) a n = 37	+1.9%	2,492 (279) a n = 33	−1.0%
No spray 10–20% Damage	2,977 (249) a n = 72	−28.4%	2,101 (139) a n = 77	−16.5%
No spray 20–30% Damage	2,157 (451) b n = 18	−48.2%	1,856 (222) a n = 18	−26.2%
No spray 30–40% Damage	No data	No data	1,458 (310) a n = 5	−42.0%

*Within each site, means followed by the same letter are not significantly different (Tukey's or Dunn's test, $P \leq 0.05$).

statistically significant differences due to very high variability among individual tree volumes ($P > 0.05$). Trees in the 20–30% damage category averaged 48.2 and 26.2% less volume than sprayed trees at sites 1 and 2, respectively, but only site 1 was statistically significant ($P = 0.004$; Table 1). At site 1, there were no trees that averaged over 30% shoot damage during the 3 years of the study. At site 2, only five trees averaged between 30 and 40% damage, with volume averaging 42% less than sprayed trees, although this was not statistically significant ($P = 0.086$; Table 1).

Average volume between damage categories by generation (i.e., average 3-year damage during the first, second, or third generation) were compared also because each tip moth generation corresponds with a loblolly pine growth flush that differentially contributes to the tree's annual growth (Asaro et al. 2003). At site 1, 3-year growth of trees averaging 20–30% damage during the first generation was significantly lower than trees averaging 0–10% or 10–20% damage ($P < 0.001$; Figure 1A). Similarly, trees averaging 10–20% or 20–30% damage during the second generation had significantly less volume than those trees averaging 0–10% damage ($P = 0.002$; Figure 1A). Finally, significant differences were present among trees averaging 0–10% damage during the third generation with those averaging 20–30% damage ($P = 0.013$). At site 2, there were no significant differences among damage categories during generations 1 ($P = 0.158$) and 3 ($P = 0.352$), although there was a decreasing trend in volume from low to high damage intervals (Figure 1B). Trees averaging 0–10% damage during the second generation had significantly greater volume than those in higher damage categories ($P < 0.001$; Figure 1B). Therefore, in general, relatively low tip moth damage sustained over the first 3 years of plantation growth had a significant effect on tree volume.

Whole-tree damage estimates generally correlate well with top-whorl estimates (Fettig and Berisford 1999b; Asaro et al. 2003). However, correlations vary depending on the study and the intensity of infestation. In addition, tip moth damage tends to be concentrated in the top whorl, which has greater impacts on tree growth and yield. Therefore, the whole-tree damage estimates reported in this study may be lower than if damage estimates had been obtained only from the top whorl, as is done in many studies to balance accuracy with labor (Asaro et al. 2003). Thus, volume impacts reported here may be associated with higher reported damage indices in other studies.

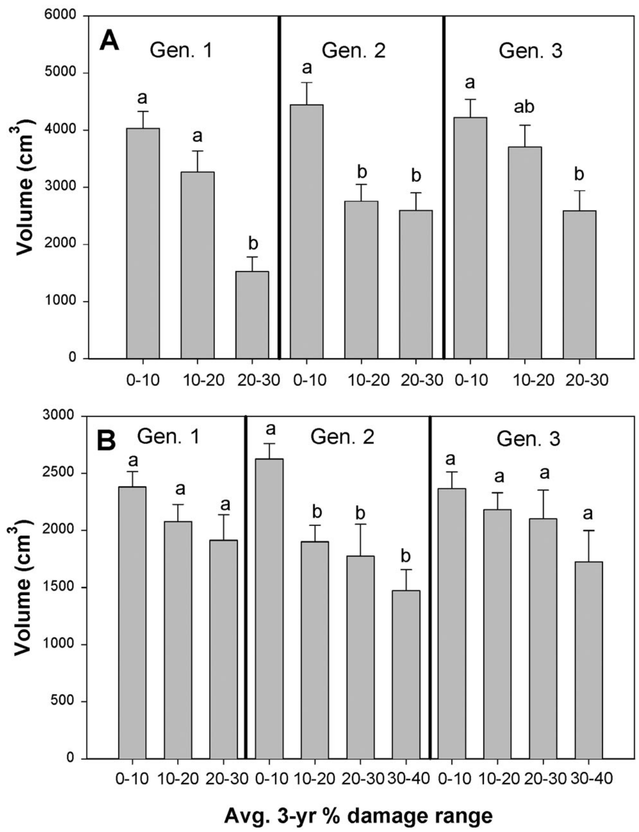

Figure 1. Average volume of 3-year-old loblolly pines by category of average damage incurred during various Nantucket pine tip moth generations at (A) site 1 and (B) site 2. The 0–10% damage category includes both sprayed and unsprayed trees. Within each site and generation, means followed by the same letter are not significantly different (Tukey's or Dunn's test; $P \leq$ 0.05).

Cost-Benefit Analysis

In all cases, the TVC, as reflected in increased LEVs, and WTP for control over one rotation were positive and significant (Tables 2 and 3). Focusing on WTP estimates, WTP

Table 2. Estimated total value of control ($/ha) resulting from reduced Nantucket pine tip moth damage to loblolly pine for sites 1 and 2 at 3, 5, and 7% real discount rates.

	Site 1			Site 2		
Damage category	3%	5%	7%	3%	5%	7%
10–20% Damage	$2,359	$1,097	$608	$874	$390	$207
20–30% Damage	$4,026	$1,845	$1,010	$1,373	$608	$321
30–40% Damage	NA	NA	NA	$2,107	$924	$484

Table 3. Estimated WTP ($/ha) to reduce loblolly pine damage from Nantucket pine tip moth over one rotation for sites 1 and 2 at 3, 5, and 7% real discount rates.

	Site 1			Site 2		
Damage category	3%	5%	7%	3%	5%	7%
10–20% Damage	$1,482	$852	$516	$586	$319	$183
20–30% Damage	$2,530	$1,433	$857	$921	$497	$284
30–40% Damage	NA	NA	NA	$1,413	$755	$429

for control increases with declining discount rates and increased damage. WTP estimates are extremely sensitive to assumptions regarding the landowner's real discount rate and the productivity of the site. Forest industry is more likely to adopt higher real discount rates than nonindustrial owners or public landowners. Therefore, focusing on the 7% rate on the lower productivity site (site 2) and assuming a damage level of 10–20%, the landowner would be willing to pay up to $183/ha to control tip moth (Table 3). At the high-end damage rate of 30–40%, they would be willing to pay up to $429/ha. On the high productivity site (site 1) and assuming a 20–30% damage level, WTP estimates soared to $857/ha (Table 3). At the highest damage levels seen in this study, optimum rotation times may be lengthened by 3–6 years, which is significant given the relatively low damage levels seen in this study. Higher damage levels would likely increase short-term impacts and incur greater economic losses, particularly because rotation times continue to decrease throughout the South (Yin and Sedjo 2001).

These data have implications for tip moth management. Many forest managers are reluctant to apply insecticides because of the expense incurred in relation to what often is perceived to be a persistent but innocuous tip moth population. Even in areas that receive consistently high levels of damage from the tip moth, insecticide use is rarely perceived as economical. Part of the reason is a lack of knowledge regarding damage thresholds and EILs for the Nantucket pine tip moth. This study suggests that damage thresholds may be significantly lower than once thought. For example, even at the lowest damage levels (10–20%) and highest real discount rates (7%), there is a WTP value of $183, which is enough to accommodate two to three sprays over a 3-year period, assuming the cost of one application of permethrin costs between $50 and 75/ha. Naturally, this analysis is very sensitive to the assumptions made, and tweaking one or more of these assumptions may result in significantly different cost-benefit calculations. We provided a range of likely parameters to present a robust analysis.

It is rare to find a loblolly pine plantation in the southeastern United States that does not have some tip moth damage (Berisford 1988, Asaro et al. 2003). Therefore, significant financial losses associated with tip moth attack are likely to be widespread. Persistent, low levels of damage from the tip moth are insidious in that they do not cause alarm as do other, more aggressive and lethal forest insects such as the southern pine beetle, *Dendroctonus frontalis* Zimmerman (Coleoptera: Curculionidae). However, small profit margins in forestry suggest that tip moth management can be important if damage levels exceed 30% of shoots infested on a regular basis. In addition, a continual reduction in the rotation length of loblolly pine grown for pulpwood or sawtimber will likely result in greater economic benefits from pest control (Fox et al. 1997).

Hedden (1998) suggests that tip moth attack in the first generation of each year is particularly harmful and that these generations are good candidates for control. He provides an economic analysis evaluating the effectiveness of planting insecticide-treated seedlings at $5.25/ha ($0.003/seedling) assuming 1,750 trees/ha are planted. Fettig et al. (2000b) suggest that spraying only the first tip moth generation or perhaps the first two generations may be enough to prevent the buildup of significant populations. Furthermore, Asaro et al. (2004) present models predicting tip moth damage levels using pheromone traps. If it is possible to predict when tip moth populations will exceed critical levels, limiting a spray schedule to one or two applications per year for the first 2 or 3 years of stand establishment may lead to significant increases in yield.

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