Revision of a Timing Model for Chemical Control of the Nantucket Pine Tip Moth (Lepidoptera: Tortricidae) in the Southeastern Coastal Plain[1]

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Abstract The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a common pest of Christmas tree and commercial pine plantations in the eastern United States (Yates et al. 1981). During the mid-1980's, a spray timing model for contact insecticides was developed to predict optimal spray dates for controlling *R. frustrana* in the southeastern Coastal Plain (Gargiullo et al. 1985). Although the model provided for generally acceptable control, analysis of the original degree-day predictions revealed that some errors occur in degree-day accumulation values used to predict insecticide spray dates. We report here the corrected values for both within-generation and cumulative year-long spray date predictions to control *R. frustrana* in locations where four generations occur annually in the southeastern United States. A similar model for the Piedmont region of Georgia where three generations occur annually accurately predicts spray dates in its current version (Gargiullo et al. 1983).

Key Words *Rhyacionia frustrana,* Nantucket pine tip moth, spray timing models, chemical control

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a common indigenous pest of Christmas tree and commercial pine plantations in the eastern United States (Yates et al. 1981). Larval feeding can cause shoot mortality and tree deformity (Berisford and Kulman 1967), reductions in height and volume growth (Stephen et al. 1982, Cade and Hedden 1987), increases in compression wood (Hedden and Clason 1980), and occasional tree mortality (Yates et al. 1981). In the Southeast, loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), and Virginia pines (*P. virginiana* Mill.) are most susceptible to infestation (Berisford 1988).

In response to demands for better tip moth control in Christmas tree plantations, a spray timing model using degree-day accumulations was developed to predict optimal spray dates for controlling *R. frustrana* in the southeastern Coastal Plain where four generations occur annually (Gargiullo et al. 1985). A degree-day is a measure of environmental heat defined as one-degree Celsius or Fahrenheit above a base temperature for a period of 24 h. Timing is critical due to the short residual nature of available insecticides and movement of developing larvae from exposed to protected areas within tree shoots. The spray timing model has helped to increase insecticide

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efficacy, reduce application frequency, and protect trees from the growth and form losses associated with late-instar larval feeding. Initially, the model was well received by Virginia pine Christmas tree growers, and later by forest industry as silvicultural practices and pine management intensified often resulting in elevated *R. frustrana* infestations that justified chemical control.

Two methods were originally developed for predicting spray timing. The first and most commonly used procedure (i. e., within-generation spray predictions) accumulates degree-day summations commencing on the date of first *R. frustrana* catch in pheromone-baited traps for each generation, and continues until an experimentally determined sum is attained (Gargiullo et al. 1985). This degree-day sum indicates the optimal spray date for each generation and is based primarily on moth phenology and insecticide properties. The second method (i. e., cumulative year-long spray predictions) predicts all four spray dates from a single biofix, i. e., the initial moth catches of the first annual generation followed by degree-day accumulations throughout the season.

Our recent attempts to use the cumulative year-long spray predictions provided by Gargiullo et al. (1985) produced some unrealistic spray date predictions. We report here reanalyses of the original data and resulting corrections of spray prediction values.

Materials and Methods

The original data presented by Gargiullo et al. (1985) were reanalyzed by two methods: (1) estimating dates from Fig. 3 of Gargiullo et al. (1985) and computing degree-day totals for these dates; and (2) determining degree-day totals for the closest evaluation date to the optimal spray date, and adjusting this value by estimating the degree-day variation between this date and the optimal spray date indicator (Gargiullo et al. 1985). Several of the dates are estimated from the original figures (Gargiullo et al. 1985), and therefore, it is possible that up to a 1 day error could occur in any estimate. Method 1 is perhaps more accurate because it does not incorporate any degree-day accumulations provided by the original paper in which errors have occurred.

We have recomputed the degree-day accumulations for both within-generation and cumulative year-long spray predictions using the 1983 weather records for Savannah, GA (National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center, Asheville, NC). The Savannah climatic data set was one of the two original data sets used by Gargiullo et al. (1985); the second was recorded at Rincon, GA ($\simeq$18 km NW of Savannah) and had very similar temperatures. The daily maximum and minimum temperatures for each day of 1983 were placed in a spreadsheet (Microsoft Excel, Microsoft Corp., Seattle, WA), and then transferred to a degree-day computational program (Degree-Day Utility, University of California Statewide Integrated Pest Management Program, Davis, CA). Degree-days were accumulated using single-sine, intermediate cutoff computation methods (Seaver et al. 1990). We also calculated degree-days by double-sine and triangular methods with intermediate, horizontal and vertical cutoffs (Seaver et al. 1990), and linear summations (Gargiullo et al. 1983) to assure that any discrepancies did not result from differences in computational methods.

Pheromone-baited trap catch data from Gargiullo et al. (1985) were used to identify the beginning of each generation, and thus serve as a biofix for the accumulation of degree-days. Traps were first deployed on 1 February and caught a sufficient number of moths on the first night to establish a biofix. Moths often emerge in early to mid-January (Berisford, unpubl. data), and it has been suggested that the original model omitted a significant number of degree-days from the first generation and cumulative year-long spray prediction values. However, January 1983 was colder than normal, and only 35 degree-days °C were accumulated by 31 January compared to 69 degree-days °C during normal years (Southeast Regional Climate Center, South Carolina Department of Natural Resources, Columbia, SC). Some moths might have emerged as early as 7 January, but a period of cooler temperatures below the flight threshold immediately followed, and it is more likely moths emerged on 29 January. This results in adding a nominal 10 degree-days °C to the first generation and cumulative year-long spray predictions.

Our degree-day computations incorporate the same lower and upper developmental thresholds (9.5 and 33.5°C, respectively) as Gargiullo et al. (1985). The lower threshold represents the average of male moth flight and egg developmental thresholds, while the upper threshold represents the maximum temperature for egg development (Haugen and Stephen 1984). When computing degree-days for the first generation and cumulative year-long spray predictions, we used the original biofix of 1 February for initial comparisons (Gargiullo et al. 1985). We provide corrected values with incorporation of the degree-day accumulations from January.

To verify that the corrected predictions were correlated with susceptible moth life stages in the field, we randomly collected one shoot from the upper whorl of 25 trees on three dates from a 2-year-old loblolly pine plantation in Taylor Co., GA. Degree-days were accumulated on site with a continuously recording biophenometer (Model T151, Dataloggers Inc., Logan, UT). Shoots were collected in 1998 during the second *R. frustrana* generation on dates that corresponded with both the original and corrected spray predictions for fenvalerate, and at the midpoint between the original and corrected spray date predictions for dimethoate. Shoots were examined in the laboratory for the presence of *R. frustrana* immatures. Larval instars were determined by head capsule measurements (Fox et al. 1971) using a dissecting microscope fitted with an ocular micrometer. These life stage data were compared with moth phenologies provided by Gargiullo et al. (1985) that correlate with effective spray timing. In the original model, optimal spray dates were determined using a regression function, and, therefore, shoot samples were not taken on each optimal spray date. However, life stage data are reported for dates surrounding the optimal spray date indicator (Gargiullo et al. 1985).

Results and Discussion

Our two evaluation methods provided similar degree-day prediction values in most cases. The mean difference between the two methods was 10 degree-days °C for fenvalerate, and 9 degree-days °C for dimethoate when comparing the cumulative year-long estimates for each spray date. The spray prediction values reported here were obtained using Method 1.

The Gargiullo et al. (1985) original spray prediction values for fenvalerate and dimethoate insecticides are shown in Table 1. The cumulative fourth generation prediction values for fenvalerate (3695.6 degree-days °C) and dimethoate (3874.5 degree-days °C) were greater than the cumulative degree-day summation for the entire year (1983; 3639 degree-days °C). Thus, it is readily apparent that the cumulative

Table 1. Degree-day accumulations* from Gargiullo et al. (1985) which predicted optimal spray dates in 1983 for fenvalerate and dimethoate insecticides to control *R. frustrana* in the Georgia Coastal Plain

	Fenvalerate prediction values		Dimethoate prediction values	
Generation	Within**	Year-long†	Within**	Year-long†
1	166.7 (300)	166.7 (300)	263.4 (474)	263.4 (474)
2	258.7 (466)	1017.6 (1832)	393.2 (708)	1152.1 (2074)
3	275.7 (496)	2335.8 (4204)	418.1 (753)	2478.2 (4461)
4	214.7 (387)	3695.6 (6652)	393.6 (708)	3874.5 (6974)

* Lower threshold 9.5 °C, upper threshold 33.5 °C, degree-days °F are shown in parentheses using a conversion factor of 1.8.

** Values are accumulated from the date on which moths were first caught in pheromone-baited traps for each successive generation.

† Values are accumulated continuously from the date on which moths were first caught in pheromone-baited traps at the beginning of the first generation.

fourth generation spray prediction values are not correct. In the southeastern Coastal Plain, fourth generation spray dates usually occur in late-August to early-September (Fettig, unpubl. data). The corrected cumulative year-long spray prediction values are reported in Table 2.

In all but one instance, the corrected within-generation spray prediction values for fenvalerate and dimethoate are greater and, therefore, would predict later spray dates than those reported by Gargiullo et al. (1985) (Tables 3, 4). The original model had previously appeared to be predicting spray dates that were too early as indicated by casual observations of tree phenology (R. S. Cameron, Union Camp Corp., Rincon, GA). Fortunately, the differences between the original and corrected within-

Table 2. Corrected degree-day accumulations* which provide cumulative year-long spray prediction values for fenvalerate and dimethoate insecticides to control *R. frustrana* in the Georgia Coastal Plain**

Generation	Fenvalerate prediction values	Dimethoate prediction values
1	237.2 (427)	364.4 (656)
2	898.8 (1618)	1041.1 (1874)
3	1756.7 (3162)	1893.9 (3409)
4	2513.3 (4524)	2715.6 (4888)

* Lower threshold 9.5 °C, upper threshold 33.5 °C, degree-days °F are shown in parentheses using a conversion factor of 1.8.

** Values are accumulated continuously from the date on which moths were first caught in pheromone-baited traps at the beginning of the first generation, and include 10 degree-days °C omitted from the original model predictions.

Table 3. Corrected degree-day accumulations* which provide within-generation spray prediction values for fenvalerate to control *R. frustrana* in the Georgia Coastal Plain**

Generation start dates (1983)	Gargiullo et al. (1985) Spray Prediction Values (GPV)	Spray date predicted using GPV and 1983 weather records	Gargiullo et al. (1985) optimal spray date from Figure 3	Corrected degree-day accumulation for column 4 date
1 February	166.7 (300)	13 March	26 March	237.2 (427)†
7 May	258.7 (466)	26 May	30 May	316.7 (570)
2 July	275.7 (496)	17 July	17 July	275.7 (496)
14 August	214.7 (387)	26 August	29 August	277.8 (500)

* Lower threshold 9.5 °C, upper threshold 33.5 °C, degree-days °F are shown in parentheses using a conversion factor of 1.8.

** Values are accumulated from the date on which moths were first caught in pheromone-baited traps for each successive generation (column 1).

† Value also includes 10 degree-days °C omitted from the original model predictions for the first generation only.

generation spray prediction values were less than those between cumulative year-long predictions. In most cases, the difference is between 2 to 5 days (Tables 3, 4), which is less problematic when considering application scheduling opportunities and unpredictable weather patterns. The exception is the large difference in terms of days that exists between the original and corrected first generation spray predictions (Tables 3, 4). However, a large spray efficacy window exists in the first generation, presumably resulting from cooler temperatures and distinct progression of life stages

Table 4. Corrected degree-day accumulations* which provide within-generation spray prediction values for dimethoate to control *R. frustrana* in the Georgia Coastal Plain**

Generation start dates (1983)	Gargiullo et al. (1985) Spray Prediction Values (GPV)	Spray date predicted using GPV and 1983 weather records	Gargiullo et al. (1985) optimal spray date from Figure 3	Corrected degree-day accumulation for column 4 date
1 February	263.4 (474)	2 April	11 April	364.4 (656)†
7 May	393.2 (708)	4 June	8 June	458.8 (826)
2 July	418.1 (753)	24 July	26 July	456.7 (822)
14 August	393.6 (708)	4 September	9 September	480.6 (865)

* Lower threshold 9.5 °C, upper threshold 33.5 °C, degree-days °F are shown in parentheses using a conversion factor of 1.8.

** Values are accumulated from the date on which moths were first caught in pheromone-baited traps for each successive generation (column 1).

† Value also includes 10 degree-days °C omitted from the original model predictions for the first generation only.

due to synchronous emergence of overwintering pupae. As a result, precise spray timing is often less critical for the first *R. frustrana* generation. Most forest managers use the within-generation prediction values because they provide more accurate spray timing predictions than the cumulative year-long estimates (Gargiullo et al. 1985). Therefore, many errors in the original model were partially mitigated in most operational insecticide applications.

The corrected spray prediction values were in close agreement with the presence of susceptible moth life stages in the field for both fenvalerate and dimethoate insecticides. The original fenvalerate spray prediction occurred at 57% egg hatch when our shoot samples contained 67% eggs and 33% first-instar larvae. The corrected fenvalerate spray prediction occurred at 59% egg hatch when life stage abundances were 75% egg, 16% first instars, 7% second instars, and 2% third instars. Gargiullo et al. (1985) provide life stage data for two dates surrounding the fenvalerate spray date for the second *R. frustrana* generation, i.e., 3 d before and 5 d after the optimal spray indicator. Life stage abundances during these dates, excluding parasitized eggs, were 90% egg, 9% first instars, and 1% second instars for the early date, and 25% egg, 42% first instars, 28% second instars, 3% third instars, and 2% fourth instars for the later date (Gargiullo et al. 1985). Our corrected fenvalerate prediction value more closely agrees with an abundance of susceptible moth life stages in the field than the original value of Gargiullo et al. (1985). Similar agreement was found between moth life stages and the corrected dimethoate spray prediction value.

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