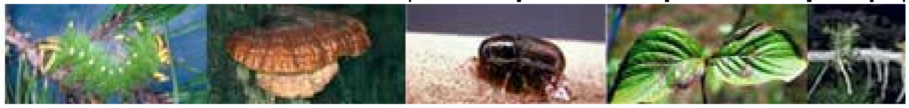

Controlling Nantucket Pine Tip Moth Infestations in the Southeastern U.S.

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Abstract

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a common pest of Christmas tree and pine plantations throughout much of the eastern U.S. As silvicultural practices intensify, insecticide applications are increasingly used to protect trees from the growth and form losses caused by larval feeding. The thermal requirements for the Nantucket pine tip moth to complete a generation were obtained from published data and used along with historical temperature data to produce maps indicating the number of annual generations predicted to occur throughout seven southeastern states. Spray timing prediction values were also obtained from published data and used to predict optimal spray periods based on 5-day increments for each location where either three or four generations occurred. Approximately 80% of the predicted optimal spray periods were within one optimal spray period of previously field-determined spray dates. Land managers who use contact insecticides, such as synthetic pyrethroids, may find the predicted optimal spray periods useful in optimizing spray effectiveness.

Key Words: chemical control**,** Nantucket pine tip moth, phenology, *Rhyacionia frustrana*, spray timing, loblolly pine, *Pinus taeda*, pine regeneration pests

Introduction

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a common pest of Christmas tree and pine plantations in the eastern U.S. (Berisford 1988). Females deposit eggs singly on needles and shoots with a significantly greater proportion being laid on needles (McCravy and Berisford 1998). The first visible signs of attack are small droplets of resin exuding from needle bases where the first instar larvae have bored entrance holes. Second instars construct silken webs which increase in size as the larvae develop. Later larval instars enter the lateral and terminal shoots where their feeding severs the vascular tissue and kills the apical meristem. Fifth instars pupate within the damaged shoots. Larval feeding can cause shoot mortality and tree deformity (Berisford and Kulman 1967), height and volume reductions (Cade and Hedden 1987), compression wood increases (Hedden and Clason 1980), and occasional tree mortality (Yates and others 1981). Damage is most severe on seedlings and saplings <5 years old (Berisford 1988). In the southeastern U.S., preferred hosts include loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), and Virginia (*P. virginiana* Mill.) pines. Slash (*P. elliottii* Engelm.) and longleaf (*P. palustris* Mill.) pines are considered resistant to attack (Berisford 1988).

Within the natural range of the Nantucket pine tip moth, the life cycle is synchronized to produce a new generation of egg laying adults during each growth flush of the primary host. Two to five generations occur annually depending on the prevailing climate (Berisford 1988). Where the moth has been studied extensively, boundaries delineating moth phenology (i.e., number of generations annually) have been well established, while in other areas this information is limited. Two generations have been reported for parts of the Mountain Province of Virginia (Berisford and Kulman 1967). Three generations occur in much of the Piedmont Plateau and Coastal Plain of Virginia (Berisford and Kulman 1967, Fettig and Berisford 1999), the Mountain Province and Piedmont Plateau of Georgia (Berisford 1974, Berisford and others 1992, Gargiullo and others 1983), and parts of North Carolina (Fettig and Berisford 1999). Four generation have been reported for the Coastal Plain of Georgia and South Carolina (Berisford and others 1992, Gargiullo and others 1985, Moreira and others 1994). Apparently, five generations occur in extreme southeastern Georgia (Ross and others 1989), the Gulf Coast, and northern Florida (Yates and others 1981). A more detailed description of Nantucket pine tip moth phenology within the range of commercially important *Pinus* species would be useful for both management and research purposes.

Insecticide applications are a viable control method if attacks cause substantial pine growth or form losses. Spray timing models have been developed to predict optimal spray dates where either three (Fettig and Berisford 1999, Gargiullo and others 1983, Dalusky, M. J. unpublished data) or four generations occur annually (Fettig and others 1998, Gargiullo and others 1985). The procedure involves accumulating degree-day summations commencing on the date of first catch in phermone-baited traps for each generation, and continuing until an experimentally determined sum is attained. The sum indicates the optimal spray date for each generation and is based on moth phenology. Spraying at about 30-80% egg hatch maximized control and corresponds with an abundance of first and second instar larvae exposed on infested shoots. These stages are most susceptible to control due to their small size, presence on the tree surface, and movement over sprayed area to new feeding sites. Spray timing models have helped to increase insecticide efficacy, reduce application frequency, and decrease the growth and form losses associated with late instar larval feeding.

Figure 1 - The author using a hand-pump backpack sprayer to control Nantucket pine tip moth infestations in a 3-year-old loblolly pine plantation.

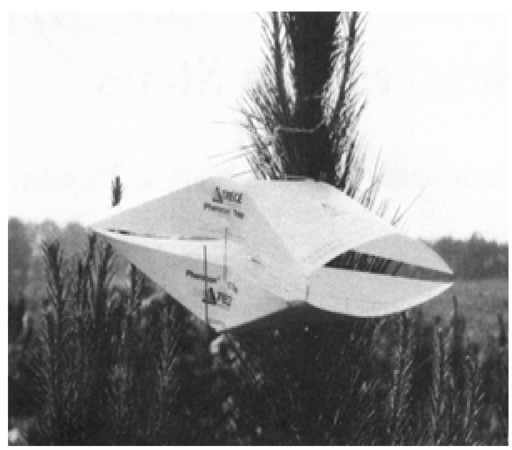

Figure 2 - A pheromone-baited wing trap used to determine male moth emergence.

The objectives of this study were to: 1) identify the number of Nantucket pine tip moth generations occurring annually based on data from weather stations located in a seven State region of the southeastern U.S., and 2) estimate optimal spray periods for each generation in locations where three or four generations occur annually.

Materials and Methods

Mean maximum and minimum temperatures for each day of the year were obtained online (http://water.dnr.sc.us; Southeast Regional Climate Center, South Carolina Department of Natural Resources, Columbia, SC) for selected weather stations in Virginia (n = 49), North Carolina (n = 58), South Carolina (n = 45), Georgia (n = 70), Alabama (n = 54), Mississippi (n = 52), and northern Florida (n = 26). The distribution of weather stations was chosen to provide a complete description of the climates that occur in each state. In most cases, mean temperature data are based on >40 years of climatic data. Weather stations with <15 years of data were excluded from analyses.

Daily mean maximum and minimum temperatures for each weather station were placed in a spreadsheet program (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 the single-sine, intermediate cutoff computation method (Seaver and others 1990) with lower and upper developmental thresholds of 9.5 and 33.5 °C, respectively (Haugen and Stephen 1984). The annual number of degree-days accumulated at each station was divided by 754 degree-days °C and rounded to the next lowest whole number to provide an estimate of the number of Nantucket pine tip moth generations occurring annually at that location (Ross and others 1989). The weather station locations and the numbers of corresponding generations were then mapped for each state.

The length of winter diapause and the precise conditions required to break it are unknown for the Nantucket pine tip moth, and temperatures above the lower developmental threshold may occur throughout the year. Therefore, spray timing prediction values were accumulated from an arbitrarily established biofix of 7 January where four generations occur annually and 1 March where three generations occur annually. Three different sets of spray timing values were used to determine optimal spray dates depending on geographic location. In portions of Virginia and North Carolina where three generations occur annually the values were 188, 784, and 1472 degree-days °C (Fettig and Berisford 1999). In remaining portions of the Southeast where three generations occur annually the values were 204, 968, and 1787 degree-days °C (Dalusky, M. J. unpublished data). In locations where four generations occur annually the values were 237, 899, 1757, and 2513 degree-days °C (Fettig and others 1998). Spray timing values are not available for controlling populations with two or five annual generations and therefore are not provided for such locations (tables 1-7). Degree-days were accumulated continuously for each weather station from the assigned biofix until the appropriate spray prediction value was reached for each generation. The corresponding date was designated the optimal spray date. Each optimal spray date was then located in an optimal spray period established by dividing the calendar year into 5-day increments.

To test the validity of spray period predictions, the predictions were compared to 44 spray dates determined at 16 different field sites during 1996-1998. The field-determined spray dates were determined on site by monitoring moth flight with pheromone-baited sticky traps (Pherecon 1 C®; Trece Inc., Salinas, CA) and accumulating degree-day totals from the initiation of moth flight for each generation with a continuously recording biophenometer (Model TA51; Dataloggers Inc., Logan, UT). During this period, mean temperatures were generally normal (1996), below normal (1997), and above normal (1998) (Athens, GA June departure from normal: -0.06 °C, -2.33 °C, and 2.06 °C, respectively) throughout most of the southeastern U.S.

Results and Discussion

Our phenology predictions indicated that the Nantucket pine tip moth would complete one to five generations annually in this region. The number of generations generally increased from northern to southern latitudes and from higher to lower elevations, but was apparently subject to variations in local topography that affect climate. The Nantucket pine tip moth is typically reported to have two to five generations annually throughout its native range (Berisford 1988). However, at Big Meadows, Virginia (elevation: 1100 m) only one generation was predicted (Station 7; fig. 3). It is unlikely that one generation would occur in Virginia since two generations are reported to occur in the northeastern U.S. (Yates 1960, Yates and others 1981). It is more likely that the thermal requirements to complete a generation that were established in more southerly latitudes at lower elevations are no longer accurate in this environment. Phenology studies conducted in northern portions of the southeastern U.S. have generally reported reduced thermal requirements to complete a generation (Fettig and Berisford 1999, Haugen and Stephen 1984). Therefore, we conclude that two to five generations occur annually in the southeastern U.S.

Virginia

Two to three generations were predicted to occur throughout Virginia (fig. 3). Two generations were predicted for the Mountain Province and agree with other studies conducted in southwest portions of the Mountain Province (Berisford and Kulman 1967, Lewis and others 1970), northern Virginia (Craighead 1950), and adjacent Maryland (Lashomb and others 1978). Three generations were predicted for much of the Piedmont Plateau and throughout the Coastal Plain (fig. 3). Studies limited to the southern portions of these regions also found that three generations occurred annually (Berisford and Kulman 1967, Fettig and Berisford 1999). Appomattox, Virginia (Station 3; fig. 3) is presumed to be an outlier because only two generations were predicted to occur there. This station is located in the Piedmont Plateau and is not associated with any particular topographic feature that would explain its cooler temperatures relative to adjacent stations. It is unknown whether this location represents a real cold pocket or if errors have occurred at the recording station. In locations with three generations, the predicted first generation spray periods generally occurred in late April, the second in mid- to late June, and the third in early August (table 1).

North Carolina

Two to four generations were predicted to occur in North Carolina (fig. 3). Two generations were predicted for the Mountain Province, and three generations throughout the Piedmont Plateau and northern two-thirds of the Coastal Plain. Fettig and Berisford (1999) identified three generations in extreme northeastern portions of the Piedmont Plateau and Coastal Plain. Four generations were predicted for a small area located in the southeastern corner of the Coastal Plain (fig. 3). The distribution of a fourth generation phenology appears to reach its northern limit in this region (Gargiullo and others 1984). Although Lumberton, North Carolina (Station 38; fig. 3) appears to be an outlier, its temperatures agree with those of adjacent Station 19 located in South Carolina (fig. 3). The location presumably indicates an actual cold pocket. Where three generations occur annually, the predicted first generation spray period generally occurred in mid-April, the second in mid-June, and the third in late July (table 2). In the few locations where a fourth generation was predicted, the first generation spray period was predicted in early to mid-April, the second in early June, the third in late July to early August, and the fourth in mid- September (table 2).

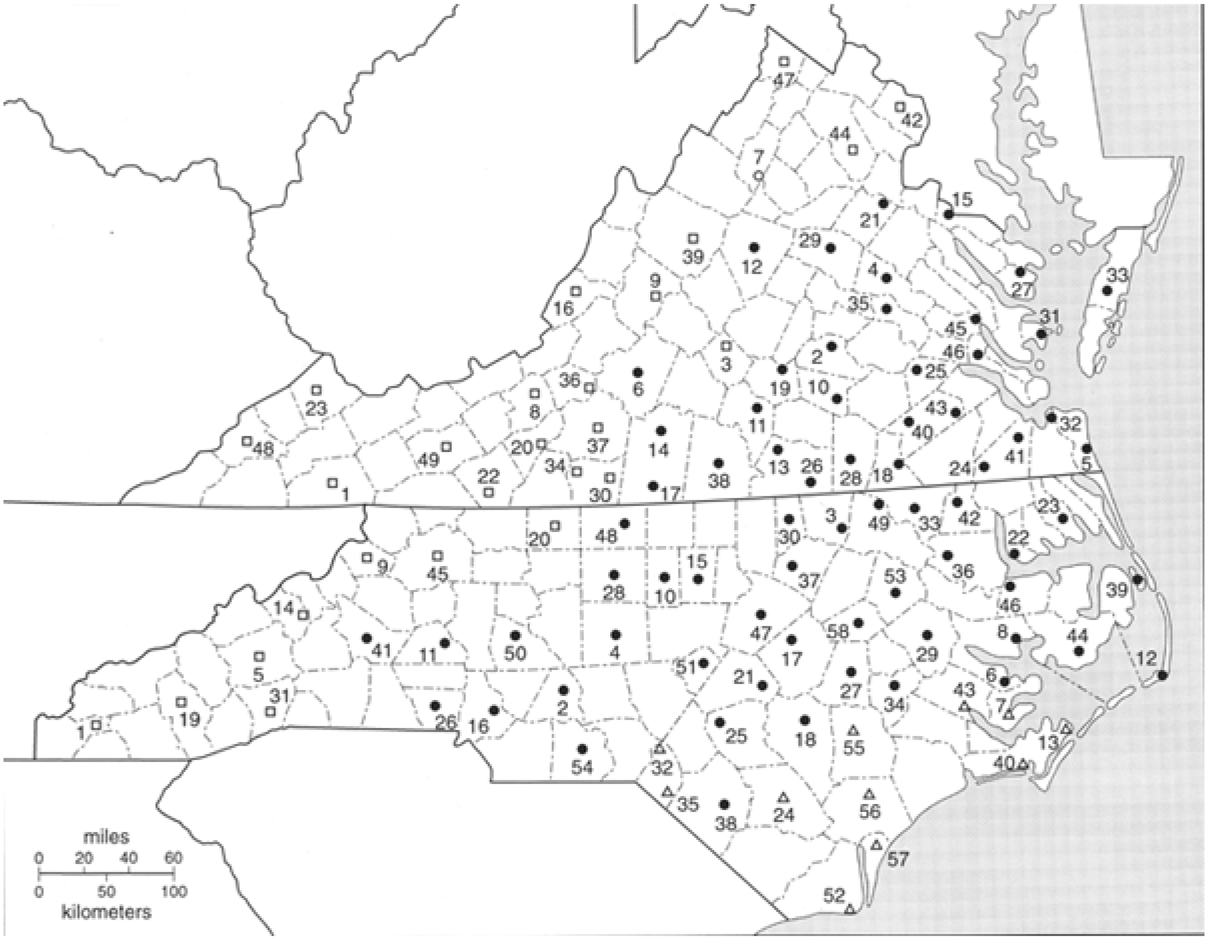

Figure 3 - Weather station locations and corresponding number of predicted Nantucket pine tip moth generations per year in Virginia and North Carolina. Open circle denotes one generation, open squares denote two generations, closed circles denote three generations, and open triangles denote four generations per year. (Numbers correspond to weather station locations in tables 1 and 2.)

South Carolina

Two to four generations were predicted to occur in South Carolina (fig. 4). Two generations were predicted for a single location (Station 8) in the extreme northwest portion of the Mountain Province (fig. 4). Three generations were predicted for much of the Piedmont Plateau, while a fourth generation occurred in most of the Coastal Plain. Four generations have previously been reported for portions of the Coastal Plain (Moreira and others 1994). Calhoun Falls and Clarks Hill, South Carolina (Stations 9 and 14; fig. 4) appear to be outliers relative to adjacent stations where three generations were predicted. However, their warmer climates could be attributed to the western proximity of Russell and J. Strom Thurmond Lakes, which may moderate temperature extremes early and late in the growing season. In locations with three generations annually, the predicted first generation spray period generally occurred in mid-April, the second in mid- to late June, and the third in early August (table 3). Where a fourth generation occurs, the predicted first generation spray period typically occurred in late March to early April, the second in late

May to early June, the third in mid- to late July, and the fourth in late August to mid- September (table 3).

Georgia

Two to five generations were predicted to occur in Georgia (fig. 4). Two generations were predicted for a single location (Station 11) at one of the highest elevations in the Mountain Province (fig. 4). Berisford and others (1992) found three generations occurred throughout the Mountain Province. This study did not include the higher elevations because they lacked significant Nantucket pine tip moth infestations. Ross and others (1989) predicted that two generations would occur throughout a more extensive area of Northeast Georgia. Three generations were predicted for much of the Piedmont Plateau and Mountain Province, which agrees with numerous studies on Nantucket pine tip moth phenologies in these regions (Berisford 1974, Berisford and others 1984, Berisford and others 1992, Canalos and Berisford 1981, Gargiullo and Berisford 1983, Gargiullo and others 1983, Kudon and others 1988). Four generations were predicted for most of the Coastal Plain except the extreme southern portions of the state where a fifth generation was predicted (fig. 4). These results are also supported by several previous studies (Berisford and others 1992, Gargiullo and others 1985, Moreira and others 1994, Ross and others 1989). Where three generations occur annually, the predicted first generation spray period generally occurred in mid-April, the second in mid- to late June, and the third in early August (table 4). In locations where a fourth generation occurs, the predicted first generation spray period typically occurred in mid- to late March, the second in late May, the third in mid- July, and the fourth in mid- August to early September (table 5).

Northern Florida

Investigations were limited to regions north of Ocala, FL (figs. 4 and 5). To the south of this region susceptible southern pine species (loblolly and shortleaf pines) become increasingly rare and an associated species of tip moth, the subtropical pine tip moth (*Rhyacionia subtropica*), becomes increasingly dominant. The limit of the natural range of the Nantucket pine tip moth occurs in Central Florida (Berisford 1988, Yates and others 1981).

Four to five generations were predicted to occur in northern Florida (figs. 4 and 5). Four generations were predicted for several locations in the western panhandle, while remaining areas appear to have five generations (figs. 4 and 5). Recent pheromone trapping programs have not revealed definitive differences in emergence patterns among the third, fourth, and possible fifth generations making it difficult to conclude how many generations actually exist (Foltz, J. personal communication). Yates and others (1981) suggested five generations occur throughout most of northern Florida. Where four generations were predicted, the first generation spray period was predicted in mid-March, the second in mid-May, the third in mid-July, and the fourth in mid-August (table 5).

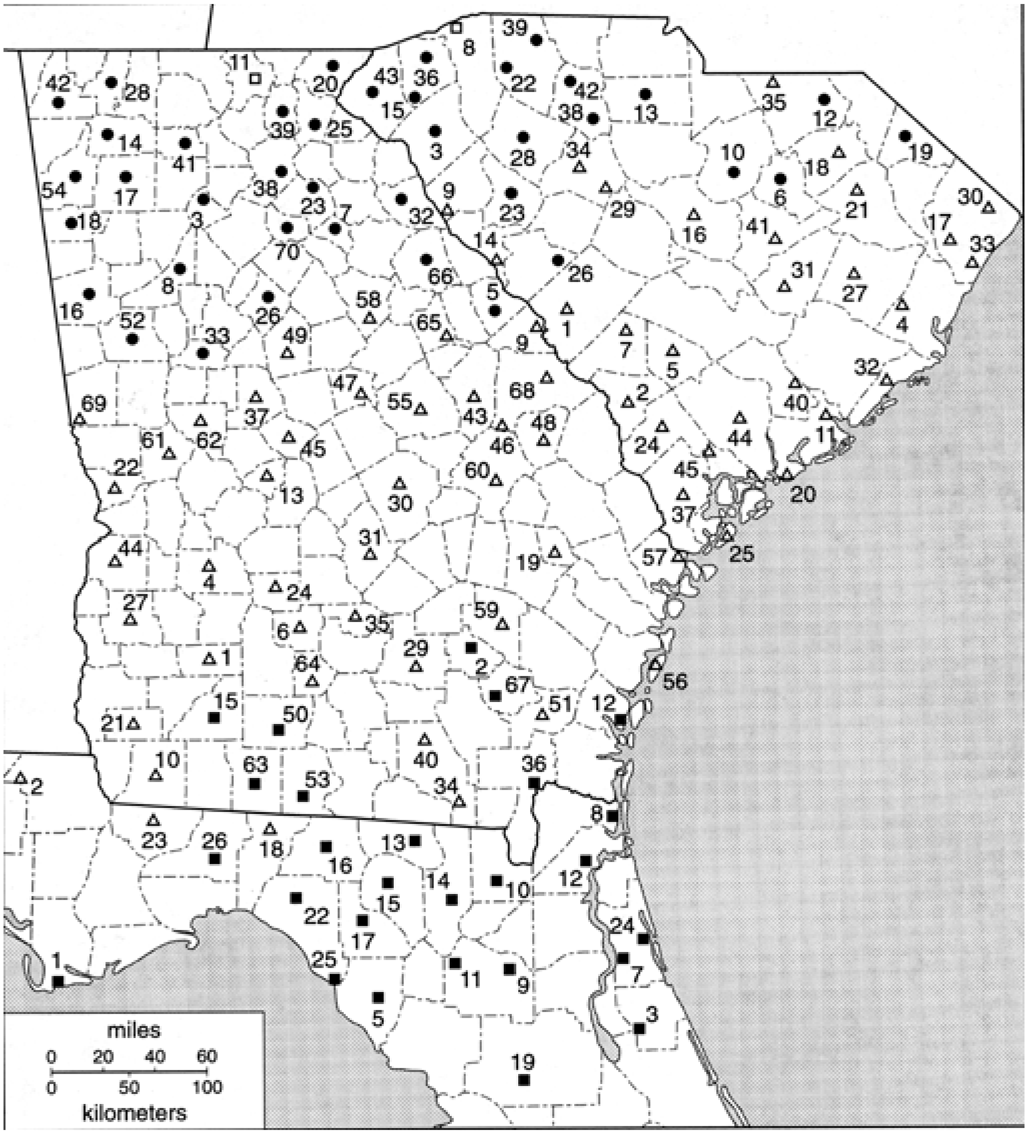

Figure 4 - Weather station locations and corresponding number of predicted Nantucket pine tip moth generations per year in South Carolina, Georgia, and northern Florida. Open squares denote two generations, closed circles denote three generations, open triangles denote four generations, and closed squares denote five generations per year. (Numbers correspond to weather station locations in tables 3, 4, and 5.)

Alabama and Mississippi

Three to five generations were predicted to occur in both Alabama and Mississippi. Three generations were predicted for northern portions of each state, and a fourth generation throughout much of the remaining Coastal Plain (fig. 5). Alexandria and Anniston, Alabama (Stations 1 and 4; fig. 5) appear to be outliers relative to surrounding stations with three generations. These stations are not associated with any particular topographic features that would explain their warmer temperatures relative to adjacent stations. They may represent actual warm pockets or errors in data acquisition may have occurred at the recording stations. Based on the close proximity of these sites (15 km) the phenology predictions are probably accurate. Hernando, Mississippi (Station 24; fig.

5) is also an outlier when compared to surrounding stations where three generations were predicted, but no particular topographic features explain its warm temperatures. A fifth generation was predicted for extreme southern portions of each state (fig. 5). Yates and others (1981) suggested that a fifth generation occurs in southern portions of the Gulf States.

In locations of Alabama and Mississippi where three generations occur annually, the predicted first generation spray period generally occurred in mid-April, the second in mid- to late June, and the third in early to mid-August (tables 6 and 7). In locations with a predicted fourth generation, the first generation spray period typically occurred in late March to early April, the second in late May to early June, the third in mid- to late July, and the fourth from late August to early September (tables 6 and 7).

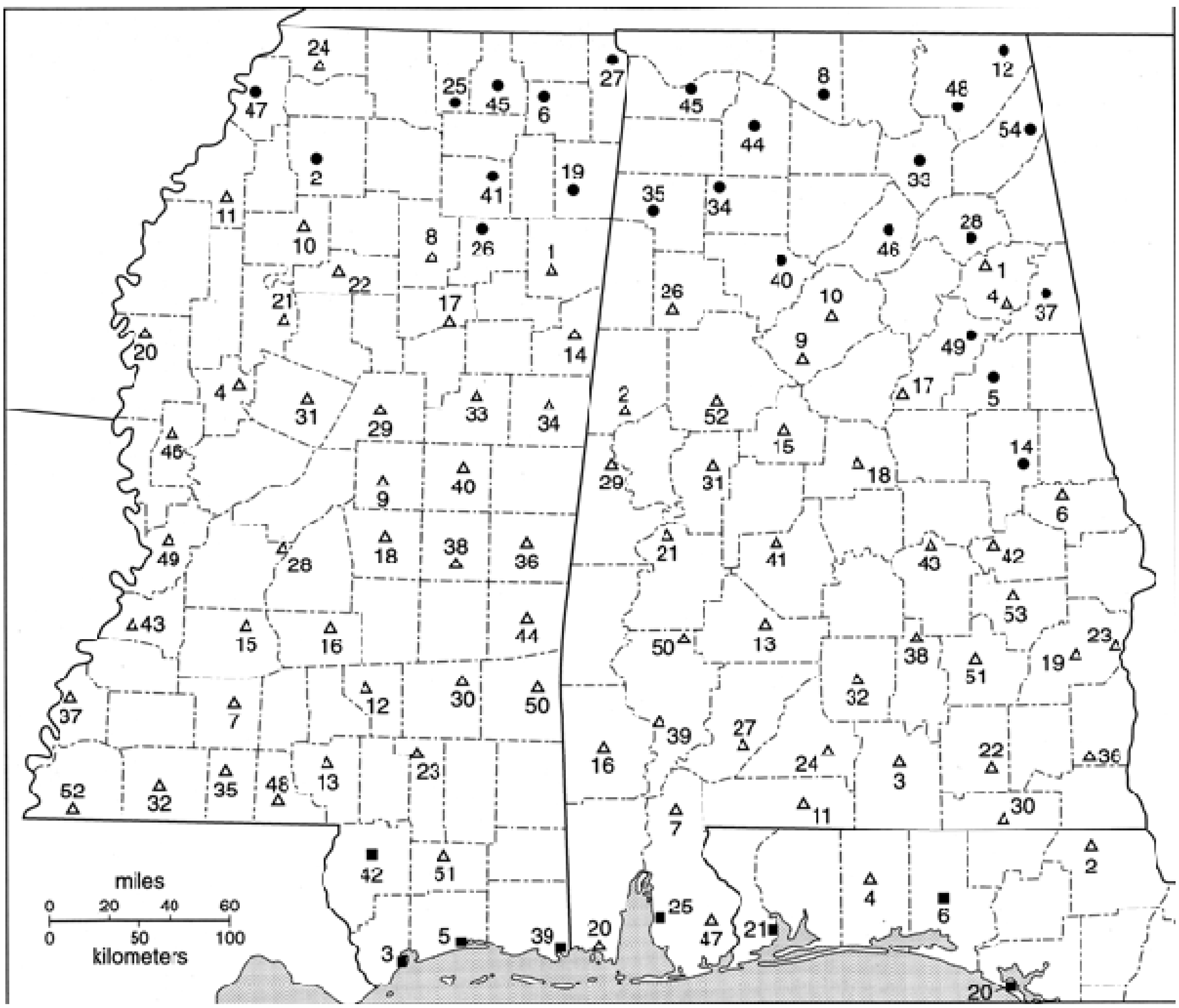

Figure 5 - Weather station locations and corresponding number of predicted Nantucket pine tip moth generations per year in northwestern Florida, Alabama, and Mississippi. Closed circles denote three generations, open triangles denote four generations, and closed squares denote five generations per year. (Numbers correspond to weather station locations in tables 6,7, and 8.)

Validity of Predictions

Fourteen (31.8%) of the predicted spray periods agreed with field-determined spray dates, 21 (47.7%) differed by one spray period, six (13.6%) differed by two spray periods, and three (6.8 percent) differed by three spray periods (table 8). Six (66.7%) of the spray predictions that differed by two or three periods occurred during the first Nantucket pine tip moth generation and may reflect discrepancies between the arbitrary biofix date and the actual initiation of moth flight at these locations. Spray timing values are typically determined experimentally by applying insecticide sprays at specified degree-day intervals, assessing damage levels for each spray, and using second degree polynomial regressions (parabolas) to determine optimal spray timing values. Although an optimal value exists, approximately 105 degree-days occur around the optimal value in which little or no variation in damage levels is observed (from Gargiullo and others 1985). Assuming a typical mean daily temperature of 15.5 °C for the first generation, 17.5 days would pass during the 105 degree-day interval. Therefore, a large spray efficacy window exists during the first generation and spray timing is often less critical.

Management Implications

Although largely effective, improper use of Nantucket pine tip moth spray timing models have occasionally led to errors in spray date predictions. These models require a detailed knowledge of moth biology, proper pheromone trap deployment (placement, spacing, and timing), intensive trap monitoring, knowledge of degree-day calculations, conversions and utility, and the ability to acquire daily maximum and minimum temperatures on or near the site. Although the collection of data required to use timing models is costly and laborious to obtain, these costs can be mitigated by increased insecticide efficacy and reduced application frequency. However, scheduling problems may still arise from short-term advance notice of approaching optimal spray dates or inclement weather patterns that limit insecticide spray opportunities.

When considering the difficulties associated with using spray timing models, the spray period predictions presented here are a viable alternative to determining optimal spray dates in the field. Land mangers applying contact insecticides, such as synthetic pyrethroids, who are unable to run the appropriate moth trapping and degree-day accumulation model can locate the closest weather station to their pine plantation (figs. 3-5), and use the optimal spray periods to time their insecticide applications accordingly (tables 1-7). During extended periods of inclement weather, you may choose to adjust the spray period predictions by one period depending on the prevailing temperature deviations from normal.

Typically, insecticides are applied during each generation for the first two or three years following stand establishment. However, Fettig and others (2000) suggest that applying a single first generation spray during the initial two years following planting may yield maximum returns. This technique would reduce the current practice by four sprays over the two year period. A complete listing of registered insecticides can be found in the current pest control handbook distributed by your State Cooperative Extension office or county agent.

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Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants and fish or other wildlife-if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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