United States
Department of
Agriculture

Forest Service

Southern
Research Station

Research Paper
SRS–32

Nantucket Pine Tip Moth Phenology and Timing of Insecticide Spray Applications in the Western Gulf Region

Christopher J. Fettig, John T. Nowak,
Donald M. Grosman, and C. Wayne Berisford

The Authors

Christopher J. Fettig, Research Entomologist, USDA Forest Service, Pacific Southwest Research Station, 1107 Kennedy Place, Suite 8, Davis, CA 95616; **John T. Nowak,** Entomologist, USDA Forest Service, Forest Health Protection, Southern Region, P.O. Box 2680, Asheville, NC 28802; **Donald M. Grosman,** Entomologist, Texas Forest Service, P.O. Box 310, Lufkin, TX 75902; and **C. Wayne Berisford,** Professor, Department of Entomology, The University of Georgia, Athens, GA 30602.

Cover:

An adult Nantucket pine tip moth (*Rhyacionia frustrana* [Comstock] [Lepidoptera; Tortricidae]). Photo by Christopher Asaro, University of Georgia, Athens, GA 30602.

DISCLAIMER

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

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.

July 2003

Southern Research Station
P.O. Box 2680
Asheville, NC 28802

Nantucket Pine Tip Moth Phenology and Timing of Insecticide Spray Applications in the Western Gulf Region

Christopher J. Fettig, John T. Nowak, Donald M. Grosman, and C. Wayne Berisford

Abstract

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a common pest of pine plantations throughout the Southern United States. The objectives of this study were to predict the phenology of *R. frustrana* populations throughout the Western Gulf region, and to provide optimal spray periods for locations that have three or four generations annually. The thermal requirements necessary to complete a generation were obtained from published data, and used in conjuction with historical temperature data to model phenology throughout the region. Four generations were predicted to occur annually throughout many of the pine producing regions of Louisiana, northeastern Texas, and southern Arkansas. Three generations were predicted for the Ozark and Ouachita Mountain ranges in Arkansas. Five generations were predicted for extreme southern portions of Louisiana and throughout southeastern Texas. 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. Tables containing the predicted optimal spray dates are provided for numerous locations within each state. Validations were conducted in Lousiana and east Texas to determine the effectiveness of this technique to achieve adequate spray timing. There was 57 percent agreement between the optimal spray periods and field-determined spray dates based on insecticide efficacy studies. Land managers who use contact insecticides, such as pyrethroids, can use these data for optimizing spray effectiveness within the Western Gulf region. This paper serves as a companion to a previously published work for the Southeastern United States (Fettig and others 2000a), and thus completes phenology and optimal spray period descriptions for *R. frustrana* throughout the Southern United States.

Keywords: Chemical control, Nantucket pine tip moth, phenology, *Rhyacionia frustrana*, spray timing.

Introduction

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a multivoltine insect that commonly infests seedling and sapling stages of southern yellow pines, particularly loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), and Virginia (*P. virginiana* Mill.) pines (Berisford 1988). The life cycle is synchronized to produce a new generation of egg laying adults with each growth flush of the primary host. This phenomenon is thought to provide each generation of developing larvae with high quality host tissues on which to feed (Asaro and others 2003). Two to five generations occur annually, depending on the prevailing climate (Berisford 1988, Fettig and others 2000a, Yates and others 1981). Generations are usually distinct, but considerable overlap may occur in regions with as few as three generations (Berisford 1988).

Bivoltine populations are found in most locations north of Maryland (Lashomb and others 1978, Powell and Miller 1978, Yates 1960), and throughout the mountain province of Virginia and North Carolina (Berisford and Kulman 1967, Fettig and others 2000a, Lewis and others 1970). Three generations occur in much of the southern Piedmont Plateau (Berisford and others 1992, Fettig and others 2000a), and in the Coastal Plain of Virginia and parts of North Carolina (Berisford and Kulman 1967, Fettig and Berisford 1999, Fettig and others 2000a). Four generations are reported for the Coastal Plain of Georgia (Berisford and others 1992), South Carolina (Berisford and others 1992, Gargiullo and others 1985, Moreira and others 1994), Alabama (Fettig and others 2000a), Mississippi (Fettig and others 2000a), and in southern California, where the insect was accidentally introduced (Malinoski and Paine 1988). Apparently, five generations occur in extreme southern Georgia (Fettig and others 2000a, Ross and others 1989), extreme southern Alabama and Mississippi (Fettig and others 2000a), perhaps along the Gulf Coast (Yates and others 1981), and in northern Florida (Yates and others 1981). Yates (1960) speculated that six generations may occur at the extreme southern edge of the range, but this has never been substantiated through field evaluations. Fettig and others (2000a) have provided a complete description of *R. frustrana* phenology throughout seven Southeastern States.

In regions where *R. frustrana* has been studied extensively, boundaries delineating phenology are fairly well established. However, in other areas such as the Western Gulf region (including Arkansas, Louisiana, and Texas), this information is lacking or poorly defined. Wallis and Stephen (1980) observed three complete generations per year in south central Arkansas. They observed a few moths emerging in September, but the majority remained in the pupal stage and emerged the subsequent spring. Trivoltine populations have also been reported to occur near

El Dorado in south central Arkansas (Warren 1964). Clarke and others (1990) reported that three complete generations per year occurred throughout Arkansas. Foil and others (1962) reported that four to five generations occurred annually in Louisiana. Sun and others (2000) suggested four generations per year occurred throughout most areas of east Texas, with a fifth generation occurring during some years based on a report by Lewis (1976). Meeker and Kulhavy (1992) reported that five generations occurred in 1986 in the vicinity of Nacogdoches, TX, based on pheromone-baited trap catches. While all of these data are available, a complete, thorough description of phenology in the Western Gulf region is lacking, but would be useful for both management and research purposes.

Ambient temperature is the abiotic factor of greatest influence on the developmental rates of poikilothermic animals (Chapman 1982). Development of all *R. frustrana* life stages occurs above 9.5 °C (Haugen and Stephen 1984, Richmond and Becheler 1989). The developmental rate curve is a characteristic sigmoid shape similar to that of many other insects (Chapman 1982). Egg and pupal development times decrease as temperature increases until a threshold of 34 °C is reached, above which both developmental rate and survivorship decrease (Haugen and Stephen 1984). Development ceases at temperatures above 36 °C. Most researchers have used lower and upper developmental thresholds of 9.5 °C and 33.5 °C, respectively (Gargiullo and others 1985, Ross and others 1989). Humidity has little effect on *R. frustrana* development (Haugen and Stephen 1984).

Estimates of the number of thermal units required to complete one *R. frustrana* generation range from 580 to 818 degree-days °C (Fettig and Berisford 1999, Gargiullo and others 1983, Gargiullo and others 1985, Haugen and Stephen 1984, Ross and others 1989). However, Ross and others (1989) determined that division of the annual number of cumulative degree-days by 754 degree-days °C, using lower and upper developmental thresholds of 9.5 and 33.5 °C, resulted in phenology predictions that correlated well with field observations in Georgia, where the moth has been studied most extensively. Likewise, Fettig and others (2000a) used the same method to map phenology in Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, and northern Florida, and reported agreement with all known published studies describing *R. frustrana* phenology in the Southeastern United States.

Insecticide applications may be justified if tip moth attacks cause substantial pine growth or form losses. There have been a number of spray timing techniques developed for *R. frustrana* based on the sequencing of phenological events. Asaro and others (2003) have provided a complete listing of degree-day spray timing models available for *R. frustrana* management. In general, the procedure involves accumulating degree-day summations starting on the date of first catch in pheromone-baited traps for each generation, and continuing until an experimentally determined sum is attained. This sum indicates the optimal spray date for each generation, and corresponds with an abundance of first and second instars (Berisford and others 1984). These stages appear most susceptible to control due to their small size, and their movement over sprayed areas while in search of 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. Pyrethroid insecticides are most commonly used in tip moth management today (Asaro and others 2003), but alternatives may be available that provide adequate control with less impact to natural enemy communities (Nowak and others 2001).

Fettig and others (2000a) have developed a system that has eliminated most of the problems and costs associated with using spray timing models. Resource managers applying contact insecticides to control *R. frustrana* infestations can simply reference a table to determine the corresponding optimal spray period (5 days) predicted for their location months or years in advance. Validation studies comparing optimal spray period predictions with those determined on site using spray timing models exceed 80 percent ± one spray period agreement (Fettig and others 2000a).

The objectives of this study were to predict the phenology of *R. frustrana* populations throughout the Western Gulf region, and to provide optimal spray periods for locations that have three or four generations annually. This paper serves as a companion to a previously published work for the Southeastern United States (Fettig and others 2000a), and thus completes phenology and optimal spray period descriptions for *R. frustrana* throughout the Southern United States.

Materials and Methods

We obtained daily temperatures from the Southern Regional Climate Center for all weather stations located in Arkansas, Louisiana, and Texas. Stations with <30 years of climatic data were excluded from further analyses. From the remaining data, the mean daily maximum and minimum temperatures were calculated for select weather stations in Arkansas ($n = 63$), Louisiana ($n = 45$), and east Texas ($n = 42$). We chose a distribution of weather stations that would provide a complete description of phenology within each state, but we were limited by the availability of data. Analyses were restricted to the portions of Texas that are located within the natural range of *R. frustrana* (Berisford 1988), which, in general, coincides with that of the loblolly pine, the primary host of *R. frustrana*.

Daily mean maximum and minimum temperatures for each weather station were placed in a spreadsheet program (Microsoft Excel®, Microsoft Corporation, Seattle, WA) and then transferred to a degree-day computational program (Degree-Day Utility, University of California Statewide Integrated Pest Management Program, Davis, CA; www.ipm.ucdavis.edu). Degree-days were accumulated using the single-sine, intermediate cutoff computation method (Seaver and others 1990), incorporating lower and upper developmental thresholds of 9.5 and 33.5 °C, respectively. The cumulative annual degree-days total was then divided by 754 degree-days °C, and rounded to the next lowest whole number to estimate the number of generations occurring annually at that location (Fettig and others 2000a, Ross and others 1989). The weather station locations and numbers of corresponding generations were then mapped for each state.

There appears to be a facultative diapause mechanism for the last *R. frustrana* generation that remains uninterrupted even when temperatures are artificially kept above the development threshold (Wallis and Stephen 1980). Unfortunately, little is known about the length of time or conditions required to terminate diapause in *R. frustrana*, and temperatures in the Western Gulf region may exceed the lower developmental threshold throughout the year. Therefore, spray timing values were accumulated from an arbitrarily established biofix of January 7 where four generations occur annually, and March 1 where three generations occur annually (Fettig and others 2000a). Although actual initial emergence dates may vary from year to year, the effect on spray date predictions is negligible, since few degree-days are initially accumulated prior to the biofix date. In three-generation phenologies, the spray timing values used for modeling optimal spray period predictions were 204, 968, and 1,787 degree-days °C (Fettig and Berisford 1999), and 237, 899, 1,757, and 2,513 degree-days °C for four-generation phenologies (Fettig and others 1998). Spray timing values are not available for controlling *R. frustrana* populations with five-generation phenologies, and therefore are not provided for such locations. Degree-days were accumulated continuously for each weather station from the assigned biofix until the appropriate spray timing value was reached. 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 (tables 1, 2, and 3).

To test the validity of our optimal spray period predictions, we selected two 2-year old loblolly pine plantations in Louisiana (L1: N31° 9.8", W92° 14.0"; L2: N31° 11.7", W92° 13.7") and Texas (T1: N31° 49.4", W95° 18.5"; T2: N31° 30.6", W94° 31.7") as validation sites. Insecticide applications were scheduled according to the optimal spray period predictions provided in tables 2 (Louisiana) and 3 (Texas) for the weather station nearest to each validation site: L1 and L2: Alexandria N31° 11.4", W92° 28.8" (approximately 29 km northwest of sites); T1: Jacksonville N31° 34.8", W95° 16.2" (approximately 16 km north of site); T2: Lufkin N31° 8.4", W94° 45.0"; T2: (approximately 26 km south-southwest of site). Insecticide treatments were applied to 50 trees at the midpoint of the predicted optimal spray period, the midpoint of the prior optimal spray period, and the midpoint of the following optimal spray period. Dates were the same for all generations and sites: March 19, 24, 29 (generation 1), May 18, 23, 28 (generation 2), July 7, 12, 17 (generation 3), and August 16, 21, 25 (generation 4). The study was designed as a randomized complete block (RCB) with four blocks and four treatments (including an untreated control group) for each generation. Treatments were made with hand-pump backpack sprayers applying permethrin (Pounce 3.2® EC, FMC Corporation, Philadelphia, PA) at a rate of 0.6 ml of formulated product per liter of water [0.17 kg (AI)/ha] to individual trees until the foliage was moist.

Damage estimates were collected on each tree during the pupal stage of each generation. The total number of shoots, i.e., > 10 linear cm of apical stem containing foliage, and number of *R. frustrana* infested shoots were recorded. Damage was expressed as the percentage of infested shoots. Means were initially computed on a per-site basis, and insecticide efficacy was calculated as percent control (control group – treatment group)/control group) * 100. The early, optimal, and late spray treatments within a generation and site were compared. If the most effective treatment resulted in < 50-percent control, that combination was excluded from analysis. The optimal spray period was considered most efficacious, i.e., optimal among treatments within a generation, when (1) efficacy was greatest, or (2) efficacy was ≥ 75 percent and damage averaged < 1.5 percent. We established these criteria based on the known efficacy of permethrin, and the normal variation inherent in these types of studies (Nowak and others 2000). Furthermore, damage estimates were arcsine square root (angular) transformed, and subjected to an analysis of variance using the Tukey test for separation of treatment means (Sokal and Rohlf 1995).

Table 1—Site number, location, phenology, and optimal spray period predictions at 63 weather stations located throughout the natural range of *Rhyacionia frustrana* (Comstock) in Arkansas

Site no.	Location[a]	Phenology	Optimal spray period intervals 1	2	3	4
1	Alicia	3	April 16-20	June 15-19	Aug. 4-8	—
2	Arkansas Post	4	April 6-10	May 31-June 4	July 20-24	Sept. 3-7
3	Beedeville	3	April 16-20	June 15-19	July 30-Aug. 3	—
4	Benton	4	April 6-10	June 5-9	July 30-Aug. 3	Sept. 13-17
5	Blakeley Mtn.	3	April 16-20	June 25-29	Aug. 9-13	—
6	Cabot	3	April 16-20	June 20-24	Aug. 4-8	—
7	Calion	4	April 6-10	June 5-9	July 25-29	Sept. 8-12
8	Camden	4	April 6-10	June 5-9	July 25-29	Sept. 8-12
9	Clarendon	3	April 16-20	June 15-19	Aug. 4-8	—
10	Conway	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
11	Corning	3	April 21-25	June 20-24	Aug. 9-13	—
12	Crossett	4	April 6-10	June 5-9	July 30-Aug. 3	Sept. 13-17
13	Dardanelle	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
14	Dermott	4	April 11-15	June 5-9	July 25-29	Sept. 8-12
15	DesArc	4	April 16-20	June 10-14	July 30-Aug. 3	Sept. 13-17
16	Dierks	3	April 16-20	June 20-24	Aug. 9-13	—
17	Dumas	4	April 6-10	May 31-June 4	July 20-24	Aug. 29-Sept. 2
18	Eldorado	4	April 6-10	June 5-9	July 25-29	Sept. 3-7
19	Eudora	4	April 6-10	June 5-9	July 20-24	Sept. 3-7
20	Eureka Springs	3	April 21-25	June 25-29	Aug. 14-18	—
21	Fayetteville	3	April 26-30	June 30-July 4	Aug. 24-28	—
22	Fordyce	4	April 11-15	June 5-9	July 25-29	Sept. 8-12
23	Fort Smith	3	April 16-20	June 20-24	Aug. 9-13	—
24	Gilbert	3	April 16-20	June 25-29	Aug. 14-18	—
25	Gravette	3	April 21-25	June 25-29	Aug. 14-18	—
26	Greenbrier	3	April 16-20	June 20-24	Aug. 4-8	—
27	Greenville, MS	4	April 6-10	May 31-June 4	July 20-24	Aug. 29-Sept. 2
28	Helena	3	April 16-20	June 15-19	Aug. 4-8	—
29	Hope	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
30	Hot Springs	4	April 16-20	June 10-14	July 30-Aug. 3	Sept. 13-17
31	Jonesboro	3	April 16-20	June 15-19	July 30-Aug. 3	—
32	Keiser	3	April 21-25	June 20-24	Aug. 4-8	—
33	Keo	4	April 11-15	June 10-14	July 25-29	Sept. 13-17
34	Leadhill	3	April 21-25	June 25-29	Aug. 9-13	—
35	Leola	4	April 11-15	June 5-9	July 25-29	Sept. 13-17
36	Little Rock	4	April 16-20	June 10-14	July 30-Aug. 3	Sept. 13-17
37	Magnolia	4	April 1-5	May 31-June 4	July 25-29	Sept. 3-7
38	Malvern	4	April 6-10	June 5-9	July 30-Aug. 3	Sept. 13-17
39	Mammoth Springs	3	April 21-25	June 25-29	Aug. 14-18	—
40	Marianna	3	April 16-20	June 20-24	Aug. 4-8	—
41	Marshall	3	April 26-30	June 30-July 4	Aug. 19-23	—
42	Mensa	3	April 21-25	June 25-29	Aug. 14-18	—
43	Monticello	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
44	Morrilton	4	April 11-15	June 5-9	July 25-29	Sept. 8-12
45	Mountainburg	3	April 16-20	June 25-29	Aug. 14-18	—
46	Mountain Home	3	April 21-25	June 30-July 4	Aug. 14-18	—
47	Mount Ida	3	April 21-25	June 30-July 4	Aug. 14-18	—
48	Newport	3	April 21-25	June 20-24	Aug. 4-8	—
49	Paragould	3	April 21-25	June 20-24	Aug. 4-8	—
50	Perry	3	April 16-20	June 20-24	Aug. 4-8	—
51	Pocahontas	3	April 16-20	June 20-24	Aug. 4-8	—
52	Portland	4	April 6-10	May 31-June 4	July 20-24	Sept. 3-7
53	Prescott	4	April 6-10	May 31-June 4	July 20-24	Sept. 3-7
54	Rohwer	4	April 16-20	June 10-14	July 30-Aug. 3	Sept. 13-17
55	St. Charles	4	April 16-20	June 10-14	July 30-Aug. 3	Sept. 13-17
56	Searcy	4	April 16-20	June 10-14	July 30-Aug. 3	Sept. 13-17
57	Stuttgart	4	April 6-10	June 5-9	July 20-24	Sept. 3-7
58	Subiaco	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
59	Texarkana	4	April 1-5	May 26-30	July 15-19	Aug. 24-28
60	Tunica, MS	3	April 16-20	June 15-19	Aug. 4-8	—
61	Waldron	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
62	Warren	4	April 11-15	June 10-14	July 30-Aug. 3	Sept. 13-17
63	West Memphis	3	April 16-20	June 20-24	Aug. 4-8	—

— = Optimal spray period interval is not applicable to three-generation phenologies.

[a] All locations are in Arkansas except those marked as Mississippi.

Table 2—Site number, location, phenology, and optimal spray period predictions at 45 weather stations located throughout the natural range of *Rhyacionia frustrana* (Comstock) in Louisiana

			Optimal spray period intervals			
Site no.	Location[a]	Phenology	1	2	3	4
1	Alexandria	4	March 22-26	May 21-25	July 10-14	Aug. 19-23
2	Ashland	4	April 1-5	May 31-June 4	July 20-24	Sept. 3-7
3	Bastrop	4	April 1-5	May 26-30	July 15-19	Aug. 24-28
4	Baton Rouge	5	—	—	—	—
5	Bienville	4	April 1-5	May 31-June 4	July 20-24	Aug. 29-Sept. 2
6	Bogalusa	5	—	—	—	—
7	Bunkie	4	March 22-26	May 21-25	July 10-14	Aug. 19-23
8	Carville	5	—	—	—	—
9	Clinton	4	March 17-21	May 16-20	July 10-14	Aug. 19-23
10	Cotton Valley	4	April 6-10	June 5-9	July 25-29	Sept. 3-7
11	Crowley	5	—	—	—	—
12	DeQuincy	4	March 17-21	May 21-25	July 10-14	Aug. 19-23
13	DeRidder	4	March 22-26	May 21-25	July 10-14	Aug. 19-23
14	Donaldsville	5	—	—	—	—
15	Elizabeth	4	March 17-21	May 21-25	July 10-14	Aug. 19-23
16	Franklin	5	—	—	—	—
17	Gorum Fort	4	March 17-21	May 21-25	July 10-14	Aug. 19-23
18	Grand Coteau	5	—	—	—	—
19	Hackberry	5	—	—	—	—
20	Homer	4	April 6-10	June 5-9	July 25-29	Sept. 3-7
21	Houma	5	—	—	—	—
22	Jeanerette	5	—	—	—	—
23	Jena	4	March 27-31	May 26-30	July 15-19	Aug. 24-28
24	Jennings	5	—	—	—	—
25	Lafeyette	5	—	—	—	—
26	Lake Charles	5	—	—	—	—
27	Lake Providence	4	April 6-10	May 31-June 4	July 20-24	Aug. 29-Sept. 2
28	Leesville	4	March 22-26	May 21-25	July 15-19	Aug. 24-28
29	Minden	4	April 1-5	May 31-June 4	July 20-24	Aug. 29-Sept. 2
30	Monroe	4	April 1-5	May 31-June 4	July 15-19	Aug. 29-Sept. 2
31	Morgan City	5	—	—	—	—
32	Nantchez, MS	4	March 17-21	May 21-25	July 10-14	Aug. 24-28
33	Natchitoches	4	March 27-31	May 21-25	July 10-14	Aug. 19-23
34	New Orleans	5	—	—	—	—
35	New Roads	5	—	—	—	—
36	Oberlin	5	—	—	—	—
37	Olla	4	March 22-26	May 26-30	July 15-19	Aug. 29-Sept. 2
38	Paradis	5	—	—	—	—
39	Plain Dealing	4	April 6-10	June 5-9	July 25-29	Sept. 8-12
40	Ruston	4	April 1-5	May 31-June 4	July 20-24	Sept. 3-7
41	St. Joseph	4	April 1-5	May 26-30	July 15-19	Aug. 29-Sept. 2
42	Shreveport	4	March 27-31	May 26-30	July 15-19	Aug. 29-Sept. 2
43	Tallulah	4	April 1-5	May 31-June 4	July 20-24	Aug. 29-Sept. 2
44	Winnfield	4	March 22-26	May 26-30	July 15-19	Aug. 29-Sept. 2
45	Winnsboro	4	April 1-5	May 26-30	July 15-19	Aug. 29-Sept. 2

— = Spray timing values are not available for areas with five-generation phenologies.
[a] All locations are in Louisiana except those marked as Mississippi.

Table 3—Site number, location, phenology, and optimal spray period predictions at 42 weather stations located throughout the natural range of *Rhyacionia frustrana* (Comstock) in Texas

			Optimal spray period intervals			
Site no.	Location	Phenology	1	2	3	4
1	Anahuac	5	—	—	—	—
2	Angleton	5	—	—	—	—
3	Aransas	5	—	—	—	—
4	Athens	4	March 22-26	May 21-25	July 10-14	Aug. 19-23
5	Austin	5	—	—	—	—
6	Bay City	5	—	—	—	—
7	Beaumont	5	—	—	—	—
8	Beeville	5	—	—	—	—
9	Brenham	5	—	—	—	—
10	Broaddus	4	March 27-31	May 26-30	July 15-19	Aug. 24-28
11	Cameron	5	—	—	—	—
12	Carthage	4	March 27-31	May 26-30	July 15-19	Aug. 29-Sept. 2
13	Center	4	March 27-31	May 26-30	July 20-24	Aug. 29-Sept. 2
14	Centerville	4	March 22-26	May 26-30	July 15-19	Aug. 24-28
15	Clarksville	4	April 11-15	June 10-16	July 30-Aug. 3	Sept. 8-12
16	Cleveland	4	March 17-21	May 21-25	July 10-14	Aug. 19-23
17	Coldspring	4	March 22-26	May 21-25	July 10-14	Aug. 24-28
18	College Station	5	—	—	—	—
19	Columbus	5	—	—	—	—
20	Corpus Christi	5	—	—	—	—
21	Corsicana	4	April 1-5	May 31-June 4	July 15-19	Aug. 24-28
22	Crockett	4	March 27-31	May 26-30	July 15-19	Aug. 24-28
23	Cuero	5	—	—	—	—
24	Daingerfield	5	—	—	—	—
25	Emory	4	April 6-10	June 5-9	July 20-24	Sept. 3-7
26	Evadale	4	March 17-21	May 21-25	July 10-14	Aug. 24-28
27	Fairfield	4	March 22-26	May 21-25	July 10-14	Aug. 14-18
28	Gilmer	4	April 6-10	June 5-9	July 25-29	Sept. 3-7
29	Greenville	4	April 11-15	June 5-9	July 25-29	Sept. 8-12
30	Groveton	4	March 17-21	May 21-25	July 10-14	Aug. 19-23
31	Hallettsville	5	—	—	—	—
32	Henderson	4	April 1-5	May 31-June 4	July 20-24	Aug. 29-Sept. 2
33	Houston	5	—	—	—	—
34	Huntsville	5	—	—	—	—
35	Jacksonville	4	March 22-26	May 21-25	July 10-14	Aug. 19-23
36	Jasper	4	March 22-26	May 21-25	July 15-19	Aug. 24-28
37	Kaufman	4	March 27-31	May 31-June 4	July 20-24	Aug. 29-Sept. 2
38	Lufkin	4	March 22-26	May 21-25	July 10-14	Aug. 19-23
39	Marlin	5	—	—	—	—
40	Mexia	4	March 27-31	May 26-30	July 15-19	Aug. 24-28
41	Mt. Pleasant	4	April 6-10	June 5-9	July 25-29	Sept. 3-7
42	Paris	4	April 11-15	June 5-9	July 20-24	Sept. 3-7

— = Spray timing values are not available for areas with five-generation phenologies.

Results and Discussion

Rhyacionia frustrana completes three to five generations annually in the Western Gulf region (figs. 1, 2, and 3). Predictions of the number of generations generally increased from northern to southern latitudes, and varied with elevation only in the Ouachita and Ozark Mountain ranges in Arkansas (fig. 1). Unlike portions of the Southeastern United States, bivoltine populations apparently do not exist in the Western Gulf region.

Arkansas

Rhyacionia frustrana populations in Arkansas were projected to have three or four generations annually (fig. 1). In many cases, phenology predictions were split along the lat. 35° N.; most locations north of that latitude having trivoltine populations, and locations south having four generations per year. Three generations were predicted for the Ouachita and Ozark Mountain ranges. However, trivoltine populations were not limited to these locations (fig. 1). The literature contains few references describing *R. frustrana* phenology in this state. Warren (1964) and Wallis and Stephen (1980) reported trivoltine populations in south central Arkansas. Clarke and others (1990) reported that trivoltine populations occurred throughout Arkansas. However, our data suggests that there are four generations per year in most of the southern half of Arkansas. This agrees with Foil and others (1962) who reported four generations in adjacent northern Louisiana. Fettig and others (2000a) have shown that phenology can vary with changes in elevation in the Southeast. Given the increases in elevation associated with the Ouachita and Ozark Mountain ranges, it is highly unlikely that trivoltine populations would exist throughout Arkansas (Fettig and others 2000a). In this study, where three generations occurred annually, the predicted first-generation optimal spray period generally occurred in mid- to late April, the second in mid-June, and the third in early August (table 1). In locations where a fourth generation occurred, the predicted first-generation optimal spray period typically occurred in early April, the second in early June, the third in late July, and the fourth in early to mid-September (table 1).

Louisiana

Most *R. frustrana* populations in Louisiana were projected to complete four generations annually (fig. 2). In general, locations north and west of Baton Rouge had four generations, while areas south and east of this location were predicted to have five generations per year (fig. 2). Foil and others (1962) reported that four to five generations occurred annually in north central Louisiana. Yates and others (1981) suggested that a fifth generation might occur in southern portions of the Gulf States. Our predictions for populations along the Mississippi border agreed with estimates provided by Fettig and others (2000a) for adjacent locations in the western portion of that State. Where four generations occurred annually, the predicted first-generation optimal spray period generally occurred in mid-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 early September (table 2)

Texas

The majority of *R. frustrana* populations in Texas were predicted to have four generations per year (fig. 3). In general, populations located north of the lat. 30° 30" N. had four generations annually, and populations south of this latitude had five generations annually. This phenology boundary agrees closely with that observed in adjacent Louisiana (fig. 2). Our predictions agreed with suggestions by Lewis (1976) and Sun and others (2000) that four-generation phenologies occur most frequently in northeastern Texas. The Daingerfield, TX station (station 24, fig. 3) is presumed to be an outlier. Five generations per year were predicted to occur at that location, but to our knowledge, this station is not associated with any particular topographic feature that would explain its warmer temperatures relative to adjacent stations. It is unknown whether this location represents a real warm pocket, or whether errors have occurred at the recording station. Where four generations occurred annually, the predicted first-generation optimal spray period generally 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 mid-August to early September (table 3).

Transition zones between phenology boundaries are not precise, and considerable deviation from temperature norms may cause slight, temporary shifts in distribution (Asaro and others 2003). Recent trapping studies as far north as Lufkin, TX, suggested that perhaps a fifth adult emergence may occur during warm years[1]. It is thought that these parent adults contribute little, if anything, to the subsequent generation. Kudon and others (1988) examined the possibility of a fourth generation in 1984 in the Georgia

---

[1] Grosman, D. 2002. Unpublished data. On file with: Donald M. Grosman, Entomologist, Texas Forest Service, P.O. Box 310, Lufkin, Texas 75902.

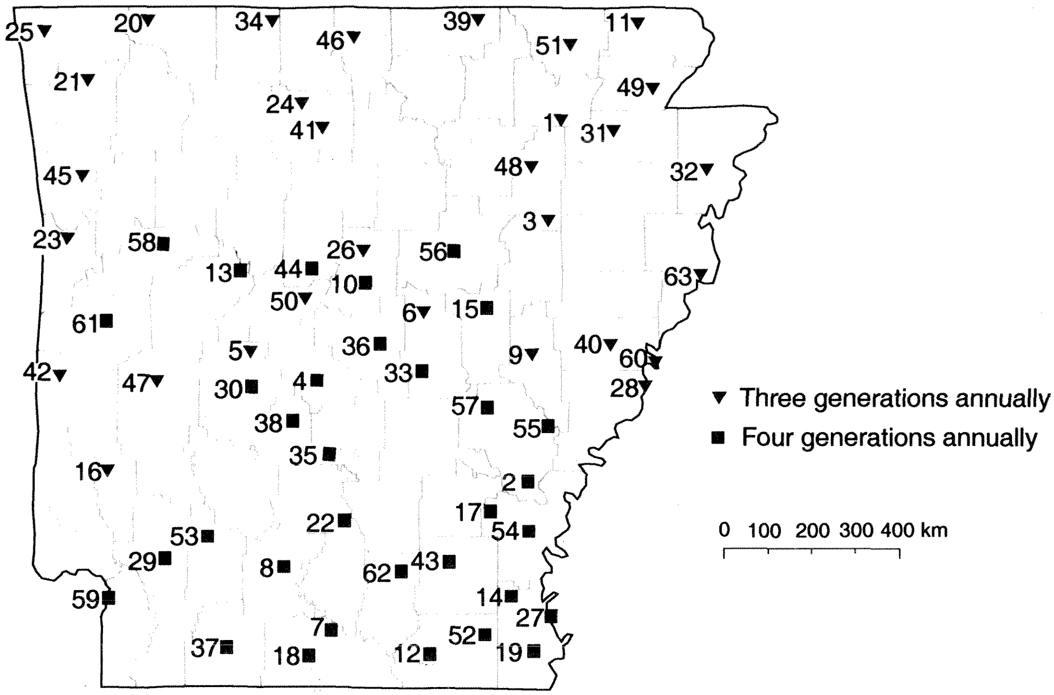

Figure 1—*Rhyacionia frustrana* phenology in Arkansas based on analysis of historical temperature data. Numbers correspond to weather station locations in table 1.

Piedmont where only trivoltine populations were thought to occur. They reported that although some additional mating and oviposition occurred, no damage was observed that could be attributed to the fourth emergence. Any such emergence would therefore likely be of minor consequence from a pest management perspective.

Validity of Predictions

Mean ± SEM damage levels (untreated control) ranged from 3.41 ± 0.89 percent to 53.47 ± 3.20 percent (table 4). Overall, damage levels were considerably lower in Texas than Louisiana. There was 57 percent agreement (8 of 14) between the optimal spray periods and field-determined spray dates based on insecticide efficacy. At one of the Texas validation sites (T1), the optimal spray periods were most efficacious during all four generations. It is interesting to note that this site was also the closest of the four to the weather station from which our predictions were generated. Data trends suggested that insecticide applications may have been more efficacious if applied 1 to 2 weeks prior to the early spray date for the third and fourth generations in Louisiana (table 4). Several factors could have contributed to this discrepancy. The closest weather station (Alexandria 1) was approximately 29 km distant, and predictions from this location simply may not have been accurate for describing temperature regimes at the field sites, particularly during the summer. Secondly, although June and July temperatures were at or near normal, May temperatures deviated + 1.2 °C from normal (Alexandria, LA, Louisiana Office of Climatology, Baton Rouge). Such deviations were not accounted for in our model, and would cause increases in *R. frustrana* development rates that would generate earlier spray dates. However, we suggest that this relatively slight increase in temperature could not be the sole cause for these discrepancies. Thirdly, although a decrease in spray efficacy is commonly observed throughout the year due to increased asynchrony among susceptible *R. frustrana* life stages (Fettig and Berisford 2002), such large decreases are rare (table 4). This suggests that perhaps the insecticide treatments applied during the third and fourth generation only achieved partial control. For example, two of these comparisons (table 4) did not meet the minimum criteria for inclusion in the agreement comparison, i.e., 50 percent control. However, the above may be of limited concern since two recent studies suggest that limiting insecticide applications to the first

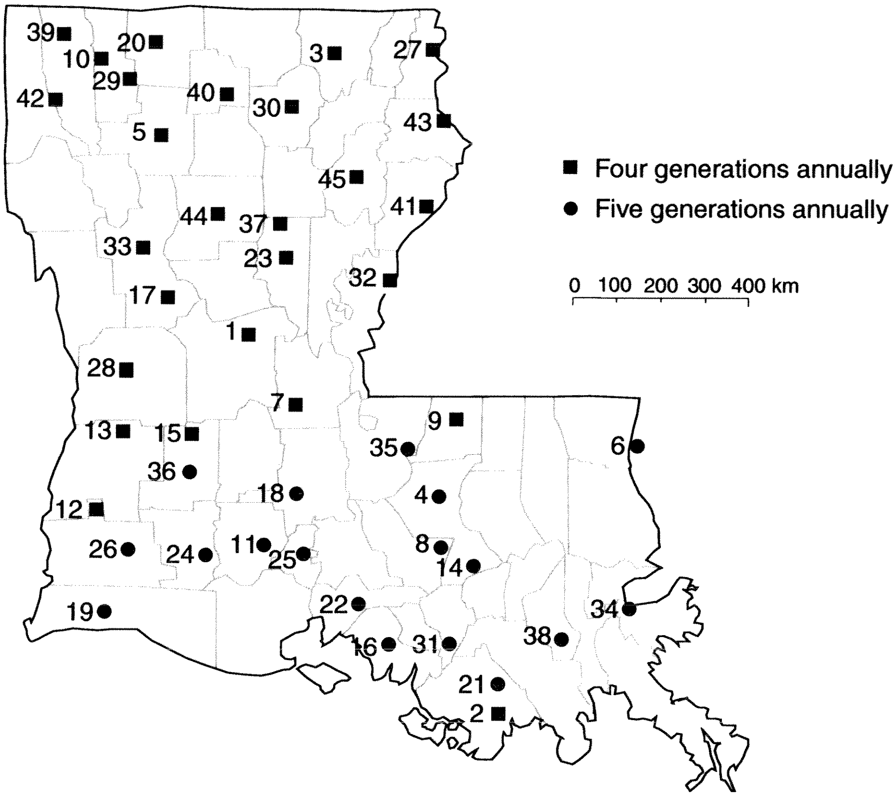

Figure 2—*Rhyacionia frustrana* phenology in Louisiana based on analysis of historical temperature data. Numbers correspond to weather station locations in table 2.

R. frustrana generation only may be the most ecologically and economically beneficial method (Fettig and Berisford 2002, Fettig and others 2000b). Optimal spray period predictions were most efficacious among all treatments during the first generation at each site (table 4).

In this study, insecticide efficacy exceeded 75 percent during 57 percent of the optimal spray periods (table 4). These data compare favorably with other studies determining the efficacy of permethrin for controlling *R. frustrana* infestations. Nowak and others (2000) developed degree-day spray timing models for permethrin in the Georgia Piedmont, and reported 62.3-percent control based on analysis of all three generations and for the three most efficacious treatment dates per generation. In a more extensive study (3,712 trees), Fettig and others (2000b) reported mean efficacy values of 90.4 percent, 77.6 percent, and 55.5 percent for permethrin for each of three generations. Unfortunately, it is difficult to compare the results of Fettig and others (2000a) to the current study, as the former was based on agreement between predicted and field-determined spray dates, and not on the effectiveness of insecticide treatments. Fettig and others (2000a) reported >80 percent ± one spray period agreement in that study.

We found a significant treatment effect during one of the four generations ($P < 0.05$; table 5). The early, optimal, and late insecticide applications were significantly different from the control, although no significant differences were detected among their treatment means (table 5). A lack of further significant differences was probably a result of our small sample size (df = 3, 9) and the large amount of variation in the data.

Management Implications

Although largely effective, improper use of various *R. frustrana* spray timing models has led to errors in spray date predictions. These models require a detailed knowledge of tip moth biology; proper pheromone trap deployment; intensive trap monitoring; knowledge of degree-day

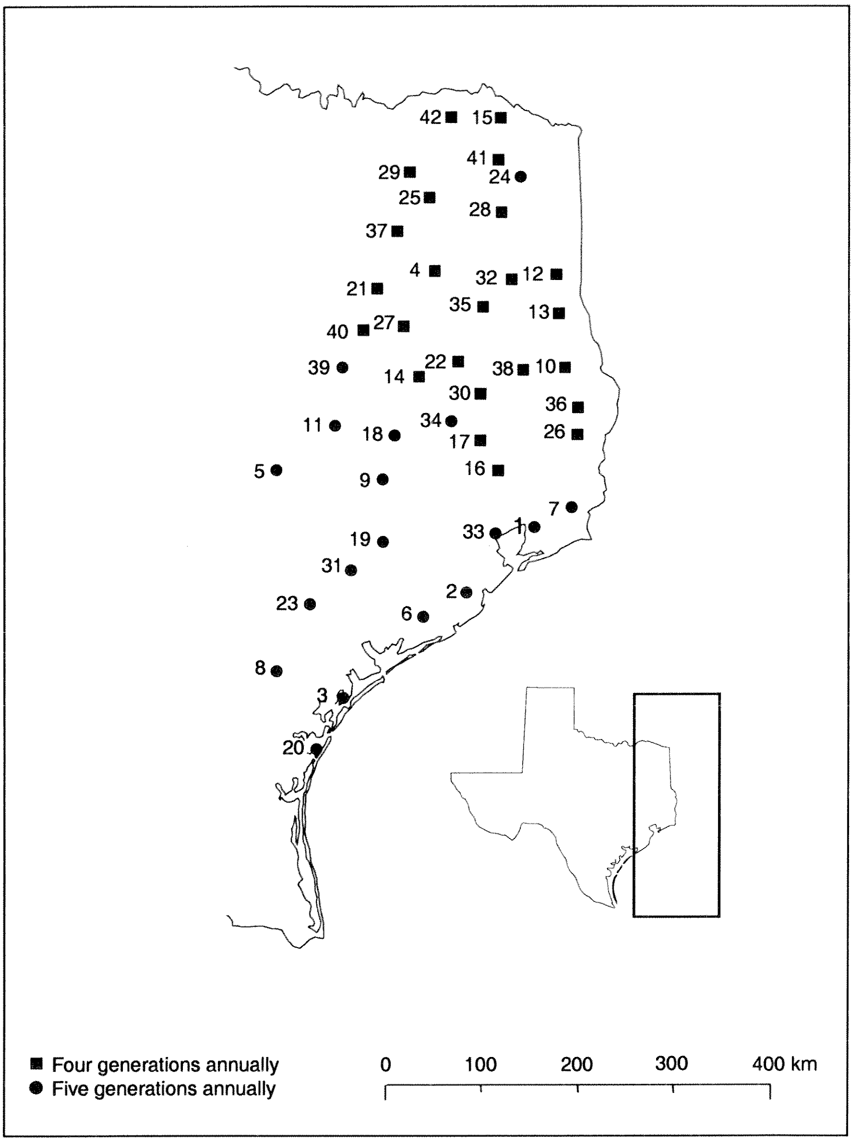

Figure 3—*Rhyacionia frustrana* phenology in Texas based on analysis of historical temperature data. Numbers correspond to weather station locations in table 3.

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, these costs can be mitigated by increased insecticide efficacy and reduced application frequency. Scheduling problems may still arise from short-term advance notice of approaching optimal spray dates; yet degree-day spray timing models still provide the best overall control providing workers invest the training, time, and resources in learning how to use them properly.

When considering these difficulties, the optimal spray period predictions presented here are a viable alternative to using spray timing models. Land managers applying contact insecticides, such as pyrethroids, can simply locate the nearest weather station to their pine plantation (figs. 1, 2, and 3), and use the optimal spray periods listed to time insecticide applications accordingly (tables 1, 2, and 3). During extended periods of inclement weather, it is advisable to adjust spray period predictions by one period depending on the prevailing temperature deviation from normal.

Table 4—Mean percent damage (± SEM) of loblolly pines (n = 50) treated with permethrin to control *Rhyacionia frustrana* at four sites in Texas and Louisiana 2002[a]

Site generation	Spray period[b] Early	Optimal	Late	Control
T1				
1	0.27 ± 0.19	**0.17 ± 0.17**	0.0 ± 0.0	8.50 ± 1.29
2	0.24 ± 0.14	**0.78 ± 0.49**	0.50 ± 0.22	12.15 ± 1.43
3	2.98 ± 0.56	**1.52 ± 0.34**	4.75 ± 0.53	5.63 ± 0.58
4	0.57 ± 0.21	**1.14 ± 0.35**	0.67 ± 0.20	10.89 ± 0.89
T2				
1	0.43 ± 0.31	**0.44 ± 0.44**	0.20 ± 0.20	3.41 ± 0.89
2	**1.30 ± 0.52**	2.30 ± 1.15	5.67 ± 1.15	7.37 ± 1.69
3	**0.23 ± 0.14**	1.35 ± 0.43	4.31 ± 0.88	3.72 ± 0.78
4	1.91 ± 0.83	1.83 ± 0.61	**0.54 ± 0.19**	6.40 ± 0.91
L1				
1	3.89 ± 1.48	**1.77 ± 0.77**	2.45 ± 1.11	18.97 ± 3.04
2	16.47 ± 2.56	**11.56 ± 2.91**	39.81 ± 3.74	34.62 ± 3.92
3[c]	14.15 ± 2.76	34.00 ± 3.80	39.90 ± 3.46	26.09 ± 2.88
4	**19.90 ± 2.71**	32.00 ± 3.25	34.75 ± 3.08	50.22 ± 3.79
L2				
1	1.71 ± 0.83	**1.00 ± 0.59**	1.19 ± 0.98	14.88 ± 2.26
2	**7.38 ± 2.02**	13.31 ± 2.88	17.41 ± 2.96	24.61 ± 3.55
3	**15.73 ± 2.84**	29.78 ± 2.98	32.44 ± 4.07	40.48 ± 2.74
4[c]	26.93 ± 2.44	29.94 ± 3.04	31.80 ± 4.04	53.47 ± 3.20

[a] T1, T2 = two sites in Texas; L1, L2 = two sites in Louisiana.

[b] Means in bold denote the most efficacious treatment within each generation based on the criteria in this research paper.

[c] Comparisons did not meet minimum criteria to indicate a most efficacious treatment.

Table 5—Mean percent damage (± SEM) of loblolly pine plantations treated with permethrin to control *R. frustrana* infestations at four sites in Texas and Louisiana, 2002. Means followed by the same letter within a row are not significantly different (RCBD; P > 0.05, Tukey's test)

Generation	Spray period Early	Optimal	Late	Control
1	1.58 ± 0.84 a	0.85 ± 0.35 a	0.96 ± 0.56 a	11.40 ± 3.44 b
2	6.35 ± 3.72 a	6.99 ± 3.18 a	15.80 ± 8.74 a	19.70 ± 6.16 a
3	8.27 ± 3.90 a	16.70 ± 8.83 a	20.40 ± 9.26 a	19.20 ± 8.83 a
4	12.30 ± 6.57 a	16.20 ± 8.52 a	16.90 ± 9.45 a	30.20 ± 12.50 a

Acknowledgments

We thank Leah Barnes (The University of Georgia) for support with data entry, Martha Shibata (U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station) for assistance with graphics, and Jay Grymes (Southern Regional Climate Center) for providing temperature data. We also thank Scott Bertrand, Dennis and Debbie Stevens, Roy O. Martin Lumber Company, and the Texas Forest Service for providing access to the field sites where validations were conducted. Christopher Asaro (The University of Georgia) and David Coyle (U.S. Department of Agriculture, Forest Service, Southern Research Station) provided helpful comments and insights on an earlier version of this manuscript. We also thank John W. Taylor, Jr., for providing advice and serving as Forest Health Protection lead contact. This research was supported by a grant funded through the U.S. Department of Agriculture, Forest Service, Special Technology Development Program (FHP-STDP-R8-2001-2).

Literature Cited

Asaro, C.; Fettig, C.J.; McCravy, K.W. [and others]. 2003. The Nantucket pine tip moth: a literature review with management implications. Journal of Entomological Science. 38: 1-40.

Berisford, C.W. 1988. The Nantucket pine tip moth. In: Berryman, A.A., ed. Dynamics of forest insect populations: patterns, causes, and implications. New York: Plenum Publication Corporation: 141-161.

Berisford, C.W.; Canalos, C.G.; Godbee, J.F., Jr.; Yates H.O., III. 1992. Occurrence and seasonal activity of pine tip moths in Georgia. For. Res. Pap. 87. Macon, GA: Georgia Forestry Commission. 11 p.

Berisford, C.W.; Gargiullo, P.M.; Canalos, C.G. 1984. Optimum timing for insecticidal control of the Nantucket pine tip moth (Lepidoptera: Tortricidae). Journal of Economic Entomology. 77: 174-177.

Berisford, C.W.; Kulman H.M. 1967. Infestation rate and damage by the Nantucket pine tip moth in six loblolly pine categories. Forest Science. 13: 428-438.

Chapman, R.F. 1982. The insects-structure and function. Cambridge, MA: Harvard University Press. 919 p.

Clarke, S.R.; Stephen, F.M.; Dunn, J.E. 1990. Spatial distribution of the Nantucket pine tip moth (Lepidoptera: Tortricidae) in newly established loblolly pine plantations. Journal of Entomological Science. 25: 209-215.

Fettig, C.J.; Berisford, C.W. 1999. Nantucket pine tip moth phenology in eastern North Carolina and Virginia: implications for effective timing of insecticide applications. Southern Journal of Applied Forestry. 23: 30-38.

Fettig, C.J.; Berisford, C.W. 2002. Use of historical temperature data for timing insecticide applications of the Nantucket pine tip moth (Lepidoptera: Tortricidae): evaluation of damage and volume increment. Journal of Agricultural and Forest Entomology. 4: 1-5.

Fettig, C.J.; Berisford, C.W.; Dalusky, M.J. 1998. Revision of a timing model for chemical control of the Nantucket pine tip moth (Lepidoptera: Tortricidae) in the southeastern Coastal Plain. Journal of Entomological Science. 33: 336-342.

Fettig, C.J.; Dalusky, M.J.; Berisford, C.W. 2000a. Nantucket pine tip moth phenology and spray timing of insecticide applications in seven southeastern states. Res. Pap. SRS-18. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 21 p.

Fettig, C.J.; McCravy, K.W.; Berisford, C.W. 2000b. Effects of Nantucket pine tip moth insecticide spray schedules on loblolly pine seedlings. Southern Journal of Applied Forestry. 24: 106-111.

Foil, R.R.; Hansbrough, T.; Merrifield, R.G. 1962. Researchers studying tip moth in loblolly pine. Louisiana Agriculture. 5: 3-4.

Gargiullo, P.M.; Berisford, C.W.; Canalos, C.G.; Richmond, J.A. 1983. How to time dimethoate sprays against the Nantucket pine tip moth. For. Res. Pap. 44. Macon, GA: Georgia Forestry Commission. 11 p.

Gargiullo, P.M.; Berisford, C.W.; Godbee, J.F., Jr. 1985. Prediction of optimal timing for chemical control of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), in the southeastern Coastal Plain. Journal of Economic Entomology. 78: 148-154.

Haugen, D.A.; Stephen, F.M. 1984. Development rates of Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae) life stages in relation to temperature. Environmental Entomology. 13: 56-60.

Kudon, L.H.; Berisford, C.W.; Dalusky, M.J. 1988. Refinement of a spray timing technique for the Nantucket pine tip moth (Lepidoptera: Tortricidae). Journal of Entomological Science. 23: 180-186.

Lashomb, J.H.; Steinhauer, A.L.; Douglas, L. 1978. Impact studies of Nantucket pine tip moth populations on loblolly pine. Environmental Entomology. 7: 910-912.

Lewis, K.R. 1976. The Nantucket pine tip moth. Fact Sheet 10M. College Station, TX: Texas A&M University, Texas Agricultural Experiment Station. 6 p.

Lewis, K.R.; Kulman, H.M.; Heikkenen, H.J. 1970. Parasites of the Nantucket pine tip moth in Virginia with notes on ecological relationships. Journal of Economic Entomology. 63: 1135-1139.

Malinoski, M.K.; Paine, T.D. 1988. A degree-day model to predict Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), flights in southern California. Environmental Entomology. 17: 75-79.

Meeker, J.R.; Kulhavy, D.L. 1992. Pine tip moth (Lepidoptera: Tortricidae) infestation rates as influenced by site and stand characteristics in loblolly pine plantations in East Texas. Environmental Entomology. 21: 534-541.

Moreira, A.F.C.; Berisford, C.W.; Hedden, R.L.; Silva, J.A.A.D. 1994. Methodology for rating *Pinus taeda* stands for pine tip moth, *Rhyacionia* spp. infestation (Lepidoptera: Tortricidae). Anais da Sociedade Entomologica do Brasil. 23: 227-236.

Nowak, J.T.; Fettig, C.J.; McCravy, K.W.; Berisford, C.W. 2000. Efficacy tests and determination of optimal spray timing values to control Nantucket pine tip moth (Lepidoptera: Tortricidae) infestations. Journal of Economic Entomology. 93: 1708-1713.

Nowak, J.T.; McCravy, K.W.; Fettig, C.J.; Berisford, C.W. 2001. Susceptibility of adult hymenopteran parasitoids of the Nantucket pine tip moth (Lepidoptera: Tortricidae) to broad-spectrum and biorational insecticides in a laboratory study. Journal of Economic Entomology. 94: 1122-1129.

Powell, J.A.; Miller. W.E. 1978. Nearctic pine tip moths of the genus *Rhyacionia*: biosystematic review (Lepidoptera: Tortricidae, Olethreutidae). Agric. Handb. 514. Washington, DC: U.S. Department of Agriculture. 33 p.

Richmond, J.A.; Becheler, J.E. 1989. A comparison of two temperature-dependent development models for immature stages of the Nantucket pine tip moth (Lepidoptera: Tortricidae). Journal of Entomological Science. 24: 117-123.

Ross, D.W.; Pickering, J.; Berg, J.D.; Berisford, C.W. 1989. Mapping Nantucket pine tip moth (Lepidoptera: Tortricidae) phenology in Georgia. Journal of Entomological Science. 24: 405-412.

Seaver, D.; Strand, J.; Strawn, A.J. 1990. Degree-day utility user's guide. Version 2. Davis, CA: University of California. 86 p.

Sokal, R.R.; Rohlf, F.J. 1995. Biometry. 3rd ed. New York: W.H. Freeman and Co. 887 p.

Sun, J.D.; Kulhavy, D.L.; Roques, A. 2000. Effects of fertilizer and herbicide application on Nantucket pine tip moth infestation (Lep., Tortricidae). Journal of Applied Entomology. 124: 191-195.

University of California Statewide Integrated Pest Management Program. 1990. Degree-day utility user's guide. Version 2. Davis, CA: University of California Statewide Integrated Pest Management Program. http://www.ipm.ucdavis.edu/WEATHER/ddretrieve.html. [Date accessed: April 1, 2003].

Wallis, G.W.; Stephen, F.M. 1980. Diapause of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), in Arkansas. Journal of the Georgia Entomological Society. 15: 454-455.

Warren, L.O. 1964. Growth of pine trees protected from attack by Nantucket pine tip moth. Arkansas Farm Research. 13: 11.

Yates, H.O., III. 1960. The Nantucket pine tip moth: a literature review. Stn. Pap. 115. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 19 p.

Yates, H.O., III; Overgaard, N.A.; Koeber, T.W. 1981. Nantucket pine tip moth. For. Insect and Dis. Leafl. 70. Washington, DC: U.S. Department of Agriculture, Forest Service. 7 p.

Fettig, Christopher J.; Nowak, John T.; Grosman, Donald M.; Berisford, C. Wayne 2003. Nantucket pine tip moth phenology and timing of insecticide spray applications in the Western Gulf Region. Res. Pap. SRS–32. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 13 p.

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), is a common pest of pine plantations throughout the Southern United States. The objectives of this study were to predict the phenology of *R. frustrana* populations throughout the Western Gulf region, and to provide optimal spray periods for locations that have three or four generations annually. The thermal requirements necessary to complete a generation were obtained from published data, and used in conjuction with historical temperature data to model phenology throughout the region. Four generations were predicted to occur annually throughout many of the pine producing regions of Louisiana, northeastern Texas, and southern Arkansas. Three generations were predicted for the Ozark and Ouachita Mountain ranges in Arkansas. Five generations were predicted for extreme southern portions of Louisiana and throughout southeastern Texas. 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. Tables containing the predicted optimal spray dates are provided for numerous locations within each state. Validations were conducted in Lousiana and east Texas to determine the effectiveness of this technique to achieve adequate spray timing. There was 57 percent agreement between the optimal spray periods and field-determined spray dates based on insecticide efficacy studies. Land managers who use contact insecticides, such as pyrethroids, can use these data for optimizing spray effectiveness within the Western Gulf region. This paper serves as a companion to a previously published work for the Southeastern United States (Fettig and others 2000a), and thus completes phenology and optimal spray period descriptions for *R. frustrana* throughout the Southern United States.

Keywords: Chemical control, Nantucket pine tip moth, phenology, *Rhyacionia frustrana*, spray timing.