NANTUCKET PINE TIP MOTH, *RHYACIONIA FRUSTRANA*, LURES AND TRAPS: WHAT IS THE OPTIMUM COMBINATION?

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Abstract—Pheromone traps are used to monitor flight activity of male Nantucket pine tip moths, *Rhyacionia frustrana* (Comstock), to initialize spray timing models, determine activity periods, or detect population trends. However, a standardized trapping procedure has not been developed. The relative efficacies of six types of lures and eight commercial pheromone traps were compared in field tests in Alabama, Georgia, South Carolina, and Virginia. Additional factors, including trap color, lure longevity and loading rates and ratios were also tested. These tests demonstrate that lures and/ or traps have a pronounced effect on male moth catches. The Pherocon 1C® wing trap was the most effective. White traps were slightly better than colored traps. Pherocon 1C® wing traps baited with commercial Scentry®, Ecogen® or Trécé® lures caught the greatest numbers of moths.

INTRODUCTION

Female NPTM Sex Pheromones and Male Response

Larvae of the Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* (Comstock), bore into and kill the shoots of loblolly pine, *Pinus taeda* L.(Yates 1960). NPTM mate shortly after they emerge from infested shoots. Female moths produce small quantities of sex pheromones that attract conspecific males for mating (Manley and Farrier 1969). Females exhibit crepuscular behavior and begin emitting their pheromones ("calling") at dusk (Berisford 1974; Berisford and others 1979). Their calling period lasts for two hours or less each day. It ends just before a sympatric species, the pitch pine tip moth, *R. rigidana* (Fernald), begins its calling period at about 1 hr after the onset of darkness (Berisford 1988). In the spring, peak male flight activity and the highest NPTM catches in pheromone-baited traps occur just before dark (Berisford and Brady 1972). NPTM fly when temperatures equal or exceed 10 EC (50 EF) (Webb and Berisford 1978). In the summer, when average temperatures are higher, male flight is later in the evening and less intense.

Berisford and Brady (1972) noted that catches of NPTM during the emergence of the overwintering generation in March and April were higher than those of later generations. They speculated that overwintering females might produce and release more pheromone than summer females. Alternatively, male response may be stronger in the spring, than during the summer, which would provide an advantage by insuring mating when NPTM populations are low. They also suggested that male catches in traps may decrease when large numbers of feral females are present to compete with the traps. Recent investigations have shown that catches in traps baited with synthetic pheromone lures are also lower during later tip moth generations even though populations are high (Asaro and Berisford 2001a).

The Pheromones

NPTM females produce a two-component sex pheromone (Berisford and Brady 1973) and their pheromone glands contain only about 20 nanograms (ng) of attractive components. Hill and others (1981) identified a straight-chain 12 carbon monoene acetate, (*E*)- 9-dodecen-1-yl acetate, (*E*9-12:OAc), as the major pheromone component in female gland extracts and a straight-chain 12 carbon diene acetate, *(E,E)*-9,11-dodecadien-1-yl acetate, (*E*9,*E*11-12:OAc), as a minor component. The components, *E*9-12:OAc and *E*9,*E*11-12:OAc occur in a 96:4 ratio in the female glands. Field tests in the Georgia Piedmont during first and second NPTM generations demonstrated that a synthetic mixture of these two compounds is as effective in attracting NPTM males, as conspecific females. Three other compounds, dodecan-1-ol, *E*-9-dodecenol (*E*9-12-OH) and dodecan-1-yl acetate, were present in the female glands but their role, if any, in pheromonal communication by NPTM remains unknown.

NPTM Lures and Traps

Tests conducted in the Georgia Piedmont during the first and second generations of NPTM show that 1.0 mg of *E*9-12:OAc plus 0.025-0.050 mg of *E*9,*E*11-12:OAc dispensed on a red rubber septum was an effective lure for NPTM (Hill and others 1981). Based upon this research, several NPTM lures are now available from commercial sources. These lures contain synthetic *E*9-12:OAc and *E*9,*E*11-12:OAc impregnated into rubber septa, plastic laminates, or dispensed from hollow glass fibers. Since the original work of Hill and others (1981), no additional field tests have been conducted to compare the performance of various lures,

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longevity of the lures, and optimum dosages and ratios the two NPTM pheromone components in other parts of the range of NPTM or for later generations. Two types of commercially available sticky traps, delta-style and wing-style, are currently used for NPTM. Tests have not been conducted to compare the efficiency of these two traps or others types of commercially available traps.

The efficiency of lures for NPTM depends on the amount and ratios of the two synthetic pheromones released. Lures that release too little pheromone will not attract moths; those that release too much may inhibit them. Research on lures for the coneworms, *Dioryctria* spp., clearly showed that catches of male moths in pheromone-baited traps are related to lure release rates (Meyer and others 1982, 1986). Lures that release the wrong ratios of the two pheromone components may also be unattractive (Hill and others 1981). Good lures can be more attractive than females. The best lures for the European pine shoot moth, *R. buoliana* (Schiffermuller), which uses the same major pheromone component as NPTM, attract 20 times more males than a single female moth (Smith and others 1974, Daterman 1974).

The amount of pheromone released per female NPTM and whether the rate of release and ratio of the two pheromones is constant for each generation is unknown. Females in later generations may be able to maintain the 96:4 natural blend, while compensating for higher ambient field temperatures by releasing more pheromone than at low temperatures. We also do not know if the quantities and natural blend of two components released by NPTM females in Piedmont Georgia are the same in other parts of its range.

Also unknown is how accurately the synthetic pheromones in NPTM lures emulate the natural blend released by females. Formulating NPTM lures is complicated because the attractive blend requires two components, and the minor component is an unstable diene. Factors that affect the rate of loss and stability of synthetic pheromones from NPTM lures include chemical structure of the pheromone, ambient field temperatures, rate of air movement over the lure, lure type, and dosage. The unique volatility of each component of Lepidoptera pheromones is determined by the length of the carbon chain, the number and position of double bonds, and the functional group. *E*9-12:OAc and *E9,E*11-12:OAc each have their own vapor pressure constants, which determine their evaporation rates from NPTM lures. Local field conditions, primarily the seasonal and diurnal fluctuations in ambient temperatures, greatly affect the pheromone loss rates and half-life of NPTM lures at any given field site and for each NPTM generation. For example, over an 8 day period polyvinyl chloride (PVC) baits lose 18 percent of their *E*9-12:OAc with daily maximum temperatures of 20–23 EC (68–74 EF), and 37 percent with daily maximum temperatures of 27–29 EC (80–85EF) (Daterman 1974). On hot summer days NPTM lures emit more pheromone than on cooler spring or fall days. Unless the half-life for *E9,E*11-12:OAc and *E*9-12:OAc are the same for a lure, the ratio of two components may change, reducing its attractiveness.

Natural or butyl rubber septa (laboratory stoppers), PVC dispensers, and laminated dispensers, such as Hercon Luretapes®, all emit pheromones by a first-order process, where the rate of evaporation is directly proportional to the amount of pheromone remaining in the lure (Butler and McDonough 1981). Natural red rubber septa are commonly used to prepare lures with Lepidoptera sex pheromones for monitoring traps. Natural red rubber septa have a large loading capacity (> 75 mg) and are composed of a cross-linked polymer that releases most straight-chain pheromones at moderate to very slow rates providing lures with a long half-life (Butler and McDonough 1981). Septa are inexpensive and can be easily loaded without highly specialized equipment. The major component of the NPTM pheromone, *E*9-12:OAc, has a 12-carbon chain and a half-life of 38 days on red natural rubber septa (Butler and McDonough 1981). The half-life for *E*9-12:OAc is almost 3 times greater on natural red rubber septa, as on PVC baits (Daterman 1974). We are unaware of any published half-life data for the minor component of the NPTM pheromone, *E9,E*11-12:OAc, on septa or PVC lures. If the half-life for *E9,E*11-12:OAc on a lure is the same as for *E*9-12:OAc the ratio of these two components released from the lure will remain constant through time. Otherwise, the ratio will change.

The dosage of 1 mg per NPTM lure (Hill and others 1981) is relatively high compared to many other forest Lepidoptera. A plastic laminate lure for gypsy moth, *Lymantria dispar* (L.), has 0.5 mg of pheromone (Leonhardt and others 1992), a red septum lure for the webbing coneworm, *D. disclusa,* has 0.1 mg of pheromone (Meyer and others 1982), and a septum lure for the spruce seed moth, *Cydia strobilella* (L.) has only 0.0003–0.003 mg (Grant and others 1989). Lures of PVC (or other non-cross-linked polymer) are useful for insects which respond to relatively high amounts of pheromone because the desired release rate can be obtained with a lower dosage per lure (Butler and McDonough 1981). The optimum release rate of *E*9-12:OAc from PVC lures was 5–56 ng/min for *R. buoliana* (Daterman 1974), but the optimum release rate for NPTM is unknown. Release rates of 30 ng/h are attractive to gypsy moths and capture rates in traps baited with PVC-twine lures remain uniform throughout a period of 16 weeks (Leonhardt and others 1992).

Laminated plastic lures, such as Hercon Luretapes®, consist of thin layers of vinyl or other polymers, with synthetic pheromone incorporated into the inner layer at 1.5 to 2.0 percent by weight (Beroza and others 1974). Laminated dispensers also follow first-order loss (McDonough 1978), but we are unaware of published data for the half-life of *E*9-12:OAc or *E9,E*11-12:OAc. In contrast, several commercial lures, such as Consept® membrane lures, Phero Tech® bubble-cap lures, and the Sentry® capillary tube or hollow-fiber lures approximate a zero-order pheromone release. Emission rate for zero-order lures is constant and independent of the concentration of the liquid pheromone (McDonough 1978), but relatively large amounts of neat pheromone are required for these dispensers, which can increase their cost.

Trap catches and degree-day models

NPTM males are present at the start of each generation, before the first females emerge and begin to lay eggs (Berisford and Brady 1972). Sticky traps baited with synthetic pheromone lures are currently deployed in intensively managed plantations of loblolly pines. Pest managers check these traps frequently to determine the beginning of each new generation. When the trap catch equals or exceeds an average of one male NPTM per trap they begin accumulating degree-days for the NPTM temperature/development models (Gargiullo and others 1984; Pickering and others 1989). These models predict the optimum dates for spraying plantations to control NPTM (Gargiullo and others 1983, 1985; Berisford and others 1984; Kudon and others 1988). A model for the coastal plain is also available (Gargiullo and others 1985).

In practice, traps baited with lures containing synthetic NPTM pheromones generally catch high numbers of male moths in infested plantations during the first and second generations, but lower and more variable catches can occur for later generations. This poor response is particularly evident in the coastal plain during the summer months (Gargiullo and others 1985), even when abundant shoot attacks suggest that NPTM populations are high (Asaro and Berisford 2001a). Male flight periods are also less distinct and often overlap for generations 3 and 4 (Gargiullo and others 1985). An alternative technique is to catch first generation NPTM males in traps, then continue accumulating degree days throughout the entire season for predicting the optimum spray dates for all four generations (Gargiullo and others 1985). Unfortunately, these predictions are not as accurate as those using models based upon the onset of each generation and in turn NPTM control is not as good. A method which uses only long-term average temperatures for timing control is also available for seven southern states (Fettig and others 2000).

High efficiency lures and traps are essential for obtaining an accurate date to begin accumulating degree-days for the NPTM models. A standard trap is also needed in order to use pheromone-baited traps for estimating relative population densities. Finally, the successful use of synthetic sex pheromones for NPTM control strategies, such as mating disruption, depend upon a clear understanding of male moth response to synthetic pheromones. The objective of our studies was to investigate some of the factors affecting catches of male NPTM in sticky traps baited with synthetic pheromones and determine promising areas for further research.

MATERIALS AND METHODS

Preparation of Custom Red and Gray Lures

Custom red and gray lures were prepared at the Forestry Sciences Laboratory, Athens, GA. The major component of the NPTM pheromone, *E*9-12:OAc (97.9 percent purity) was purchased from Bedoukin Research Inc., Danbury, CT. The minor component, *E*9,*E*11-12:OAc (88.4 percent purity), was purchased from Chemteck B. V., Amsterdam, The Netherlands. Purity was verified using a Hewlett-Packard GC-MS. The neat synthetic pheromones were stored at - 40 EC until used to formulate pheromone solutions for the custom red and gray septa lures. Red, natural rubber sleeve-type septa, 1.9 by 1 cm (Arthur H. Thomas, Philadelphia, PA) and gray, sleeve-type septa, 1.9 by 1 cm, composed of a halo-butyl isoprene blend elastomer (West Company, Phoenixville, PA) were labeled with a treatment code using a black permanent marking pen.

Stock solutions containing *E*9-12:OAc and *E*9,*E*11-12:OAc in nanograde dichloromethane were prepared and dispensed in 0.1 ml aliquots into the well of each septum. Two additional 0.1 ml aliquots of the solvent were added to each well to insure that any residual pheromone was impregnated into the septa (Brown and McDonough 1986). Loaded septa were allowed to age for 48 hours in a laboratory fume hood (20–24 EC) and then they were wrapped in aluminum foil, placed in labeled glass screw-top bottles, and stored at -40 EC. The first batch of custom gray and red septa lures were prepared on 5 February 1997; a second batch of lures were loaded on 8 May 1997 because we decided to include more tests sites than originally planned. Custom red septa lures from batch 2 were used in tests 6, 9, 11, and 12; custom gray lures from batch 2 were used in tests 6, 11, and 12.

Experimental Design

Each field test was installed in a 2- or 3-year-old loblolly pine plantation with approximately 700 trees per acre. Rows of trees served as a block in a randomized complete block design. Trap positions equal to the number of treatments in the test were established by marking every fifth tree within the row with colored flagging. One row of trees without traps was left between each row of trees with traps. Within each block (row), treatments were randomly assigned to each position. The treatments were rerandomized each time the traps were checked by moving the traps to new positions. Each field test had 5 replicates per treatment, except for the trap design and color tests, which had 6 replicates per treatment.

Trapping Procedure

At each trap position within a test site, a single trap was hung in the tree, near the top, and at approximately the same height (1.0–1.4 m) and cardinal direction relative to the tree stem. The total number of traps used in each test equaled the number of treatments times the number of replicates (blocks). Lures were stored in a freezer and transported to the field in a cooler with ice. Disposable rubber gloves were worn while handling the lures and were changed for each kind of lure. A 1 cm hole was punched in the top of each of the Pherocon 1C traps®, Pherocon CP traps®, Pherocon II traps®, and the Trécé Delta traps® so that a paper clip could be used to suspended a lure from the trap top and prevent it from contacting the sticky trap bottom. New traps and lures were deployed for each test. Traps were checked twice a week at 3–4 day intervals. NPTM caught in the traps were removed and the numbers were recorded on each day the traps were checked.

Commercial and custom NPTM lure tests

Twelve field tests were conducted during 1997–98 to compare commercial and custom NPTM lures. Commercial lures were purchased from Gempler's Inc., Mt. Horeb, WI and Great Lakes IPM, Vestaburg, MI; each custom red or gray septum lure was loaded with 1 mg of synthetic *E*9-12:OAc and *E*9,*E*11-12:OAc (20:1) as described above. Five to seven of the following treatments were included in each test: 1) Hercon Luretapes® (Hercon Environmental Corp., Emigsville, PA), 2) Scentry® hollow fiber lures, 3) Trécé Red Septa® NPTM lures (Trécé Incorporated, Salinas, CA), 4) Ecogen® Red septa lures (Ecogen Inc., Columbia, MD), 5) Custom Red septa, 6) Custom Gray septa, and 7) Control (unbaited trap). Pherocon 1 C® wing traps (with white plastic top) were used for all treatments. Tests were conducted at sites in Bulloch County, GA; Madison County, GA; Oconee County, GA; Oglethorpe County, GA, Bulloch County, AL, Macon County, AL, Beaufort County, SC; and Southhampton County, VA.

Trap Design Tests

Two field tests were conducted to compare catches of male NPTM in eight commercial traps (fig. 1). Traps were purchased from Gempler's Inc., Mt. Horeb, WI or Great Lakes IPM, Vestaburg, MI. Eight treatments with the following traps were tested: 1) Pherocon 1 C® wing trap (with white plastic top), 2) Pherocon 1C® wing trap (with brown plastic top), 3) Pherocon CP® wing trap (white), 4) Trécé Delta® trap (orange), 5) Trécé Delta® trap (green), 6) Trécé Pherocon II® trap (white), 7) Pherocon Bucket® trap (yellow/white), and 8) Pherocon Bucket® trap (green). Assembly of all traps followed the printed instructions included with the traps. Cattle ear tags containing dichlorvos (DDVP) insecticide (Y-Tex Corporation, Cody, WY) were cut in thirds and one piece was placed in the bottom of each bucket trap to kill the moths caught in the traps. Trécé red rubber septa were used as lures in all of the traps. The tests were conducted from 20 May – 29 June, 1998 in Oglethorpe County, GA and from 15 May – 9 June, 1998 in Bullock County, AL during the emergence of the second generation of NPTM.

Trap Color Tests

Two field tests were conducted to compare catches of male NPTM in Pherocon 1 C® wing traps painted with eight different colors. Treatments included: 1) Red, 2) Yellow, 3) Green, 4) Orange, 5) White, 6) Black, 7) Blue, 8) Gray, and 9) Unpainted (Control). All colors except orange were ColorPlace® fast-drying spray paint (WalMart, Bentonville, AK). Orange paint was not available in that brand so Krylon® interior/exterior spray paint (Sherwin-Williams, Cleveland, OH) was used. The traps were painted one week prior to the tests and left outdoors to allow the paint vapors to dissipate. The first test was conducted from 26 June to 24 July, 1998 in Bullock County, AL. during the emergence of the second NPTM generation. The second test was conducted at the same site from 7 August – 4 September, 1998 during the emergence of the third NPTM generation.

Lure Longevity Test

One field test was conducted to compare the effects of lure longevity on catches of male NPTM in Pherocon 1 C® wing traps. There were three treatments: 1) Trécé Red Septa® NPTM lures replaced weekly, 2) Trécé Red Septa® NPTM lures unchanged, 3) unbaited (Control). The test was conducted in Macon County, AL from 11 July to 8 August, 1997.

Optimum Dosage and Ratio of *E*9-12:OAc : *E*9,*E*11-12:OAc Tests

A field test was conducted to compare the effects of several dosages of *E*9-12:OAc : *E*9,*E*11-12:OAc on catches of male NPTM in Pherocon 1 C® wing traps. Custom Red rubber septa lures were loaded with synthetic NPTM pheromones for six treatments with dosages of *E*9-12:OAc : *E*9,*E*11-12:OAc (20:1) per lure: 1) 2 mg, 2) 1 mg, 3) 0.5 mg, 4) 0.25 mg, 5) 0.125 mg, and 6) unbaited trap (Control). The test was conducted in Oconee County, GA 20 March to 5 May, 1997.

A second test was conducted to compare the effects of *E*9-12:OAc : *E*9,*E*11-12:OAc ratios on catches of male NPTM in Pherocon 1 C® wing traps. Custom Red rubber septa lures were loaded with 1 mg of synthetic NPTM pheromones for six treatments with ratios of *E*9-12:OAc : *E*9,*E*11-12:OAc: 1) 5:1, 2) 10:1, 3) 20:1, 4) 40:1, 5) 80:1, and 6) unbaited trap (Control). The test was conducted in Oconee, GA 20 March to 5 May, 1997.

Data analyses

Treatment means and standard errors (± SE) were calculated for each test. Trap catches of male NPTM were transformed by $\log_e (x + 1)$ to meet the assumptions of analysis of variance (ANOVA) and analyzed using PROC GLM for randomized complete block designs, followed by the Tukey test at " = 0.05 (SAS Institute 1990).

RESULTS

There were significant differences ($F_{44,248} = 5.59$, $P = 0.0001$) in catches of NPTM among rows (blocks) within each of the 12 Lure tests. In all of our field tests, traps in the two outer rows of trees generally caught more moths than traps placed in trees located in interior rows.

Commercial and custom NPTM lure tests

There were significant differences in trap catches among traps baited with the various lures treatments in 10 of our 12 Lure tests (fig. 2–5): Test # 1 $F = 3.48$, $P = 0.0315$; Test # 2 $F = 1.26$, $P = 0.3213$; Test # 3 $F = 4.68$, $P = 0.0108$; Test # 4 $F = 4.89$, $P = 0.0090$; Test # 5 $F = 1.82$, $P = 0.1547$; Test # 6 $F = 12.96$, $P = 0.0001$; Test # 7 $F = 5.59$, $P = 0.0022$; Test # 8 $F = 7.67$, $P = 0.0004$; Test # 9 $F = 10.02$, $P = 0.0001$; Test # 10 $F = 10.88$, $P = 0.0.0002$; Test # 11 $F = 9.10$, $P = 0.0001$; and Test # 12 $F = 5.46$, $P = 0.0025$.

In nine of the tests, control traps without lures caught few moths, but mean catches per trap were 10.8 ± 2.1 for generation 1 (Test #9) in Alabama, and 10.6 ± 2.6 for generation 1 (Test #10) and 23.6 ± 10.9 generation 2 (Test #11) in Virginia. NPTM populations were very high during these three tests and trap catches for the best lures in each test were 9 to 28 times those for the control traps.

No single lure was best in all locations and generations and there was a significant treatment by location interaction ($F_{56,248} = 8.50$, $P = 0.0001$). Traps with the Trécé® red septa lures, Ecogen® red septa lures, and Sentry® fiber lures caught significantly higher numbers of moths than the Hercon luretapes® (figs. 2–5). Custom red and gray septa lures from batch 1 performed well (figs. 2–5), and catches in

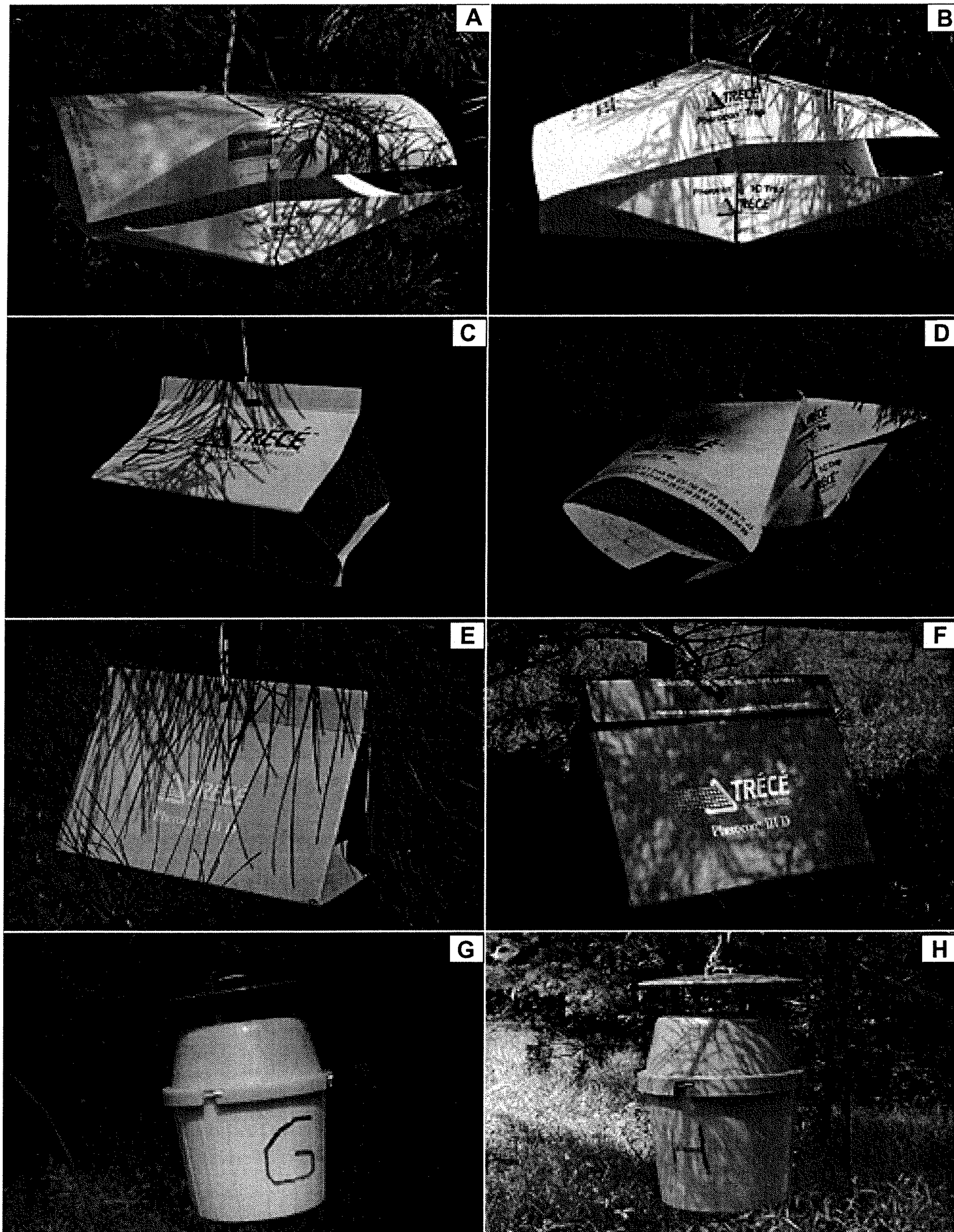

Figure 1—Commercial traps used in the trap design tests: (A) Pherocon 1 C® wing trap (with brown plastic top), (B) Pherocon 1C® wing trap (with white plastic top), (C) Trécé Pherocon II® trap (white), (D) Pherocon CP® wing trap (white), (E) Trécé Delta® trap (green), (F) Trécé Delta® trap (orange) (G) Pherocon Bucket® trap (yellow/white), and (H) Pherocon Bucket® trap (green).

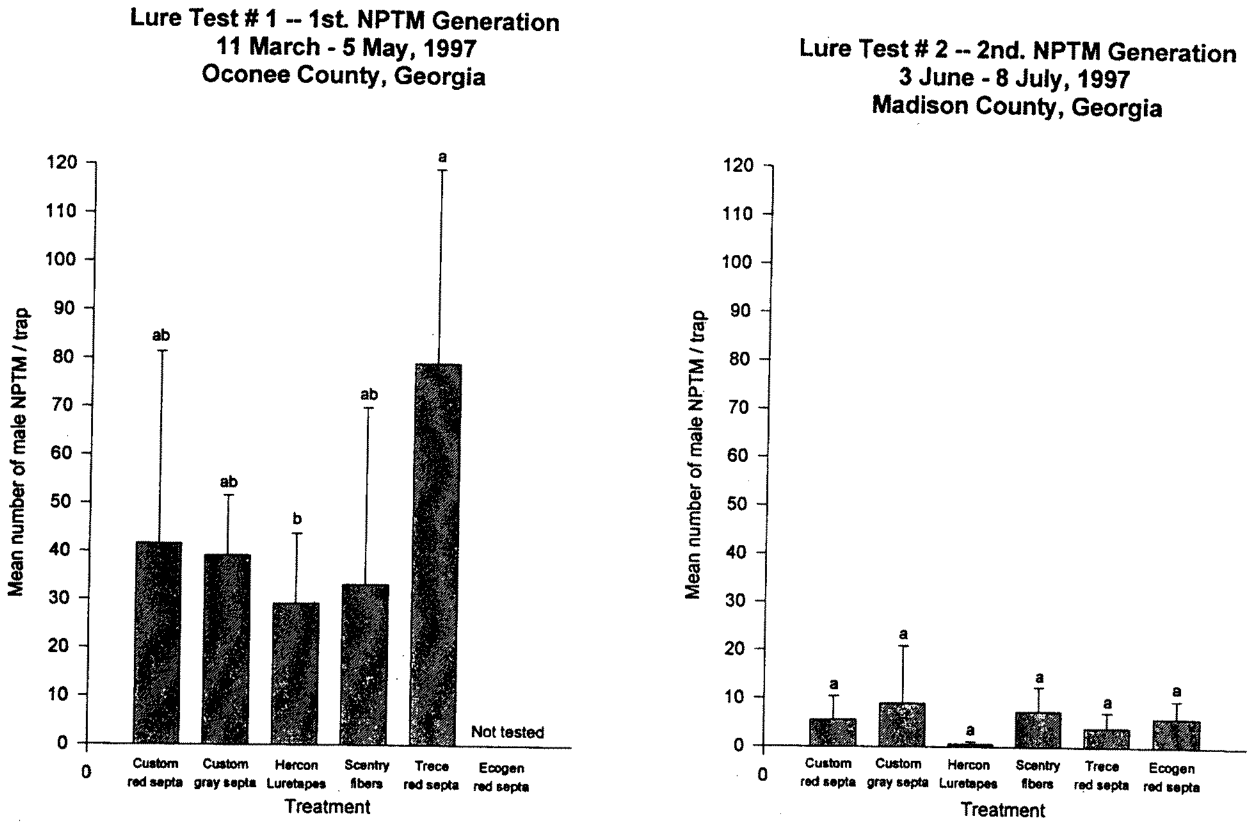

Figure 2—Catches of NPTM males in Pherocon 1C® wing traps baited with custom and commercial lures, Georgia Piedmont, 1997.

traps with the three best commercial baits were generally not significantly different from the batch 1 custom lures. Custom lures from batch 2 performed poorly in all tests where they were used (custom red septa lures, tests 6, 9, 11, and 12 and custom gray, tests 6, 11, and 12), apparently because these septa were improperly loaded.

Trap Design Tests

Catches differed significantly among treatments in Trap Design Test # 1 (F = 15.26, P = 0.0001) and Trap Design Test # 2 (F = 16.73, P = 0.0001). Pherocon wing traps®, with either the white or brown top, captured significantly more moths than the other traps tested in both tests (fig. 6). The Pherocon II® trap captured only about half as many moths as wing traps. Other traps tested were less effective and caught significantly fewer moths than the wing traps. The poorest traps were the orange and green Trécé Delta Traps®, and the Pherocon Green Bucket® trap. These traps were also late in predicting first male NPTM catches in both tests (table 1).

Trap Color Tests

Catches differed significantly among treatments in Color Test # 1 (F = 4.86, P = 0.0003) and Color Test # 2 (F = 3.94, P = 0.0016). Pherocon 1 C® wing traps painted red, yellow, blue or gray caught significantly fewer moths than unpainted traps in Color Test #1, but only blue or gray traps had lower catches in Color Test # 2 (fig. 7). Unpainted Pherocon 1 C® wing traps consistently caught more moths than painted traps. Gray traps had the lowest catches.

Lure Longevity Test

Catches of NPTM males in Pherocon 1 C® wing traps with Trécé Red rubber NPTM lures were replaced weekly did not differ significantly (F = 2.2, P = 0.2049) from those for traps where the lures were not changed (fig. 8). Differences in the mean number of NPTM males caught per trap between treatments, within each trapping period were similar and the treatment by trapping period interaction was not significant (F = 0.0, P =0.947).

Optimum Dosage and Ratio of *E*9-12:OAc : *E*9,*E*11-12:OAc Test

Catches of NPTM males in Pherocon 1 C® wing traps differed significantly among treatments (F = 3.30, P = 0.020) with red rubber septa lures containing different dosages of *E*9-12:OAc : *E*9,*E*11-12:OAc (20:1). The treatment by trapping period interaction was not significant (F = 0.91, P = 0.637). Traps with the 0.125mg lures caught significantly more moths than traps without lures or with 1mg lures (fig. 9). There was no significant difference among catches for traps with 0.125, 0.25, 0.5, or 2 mg lures.

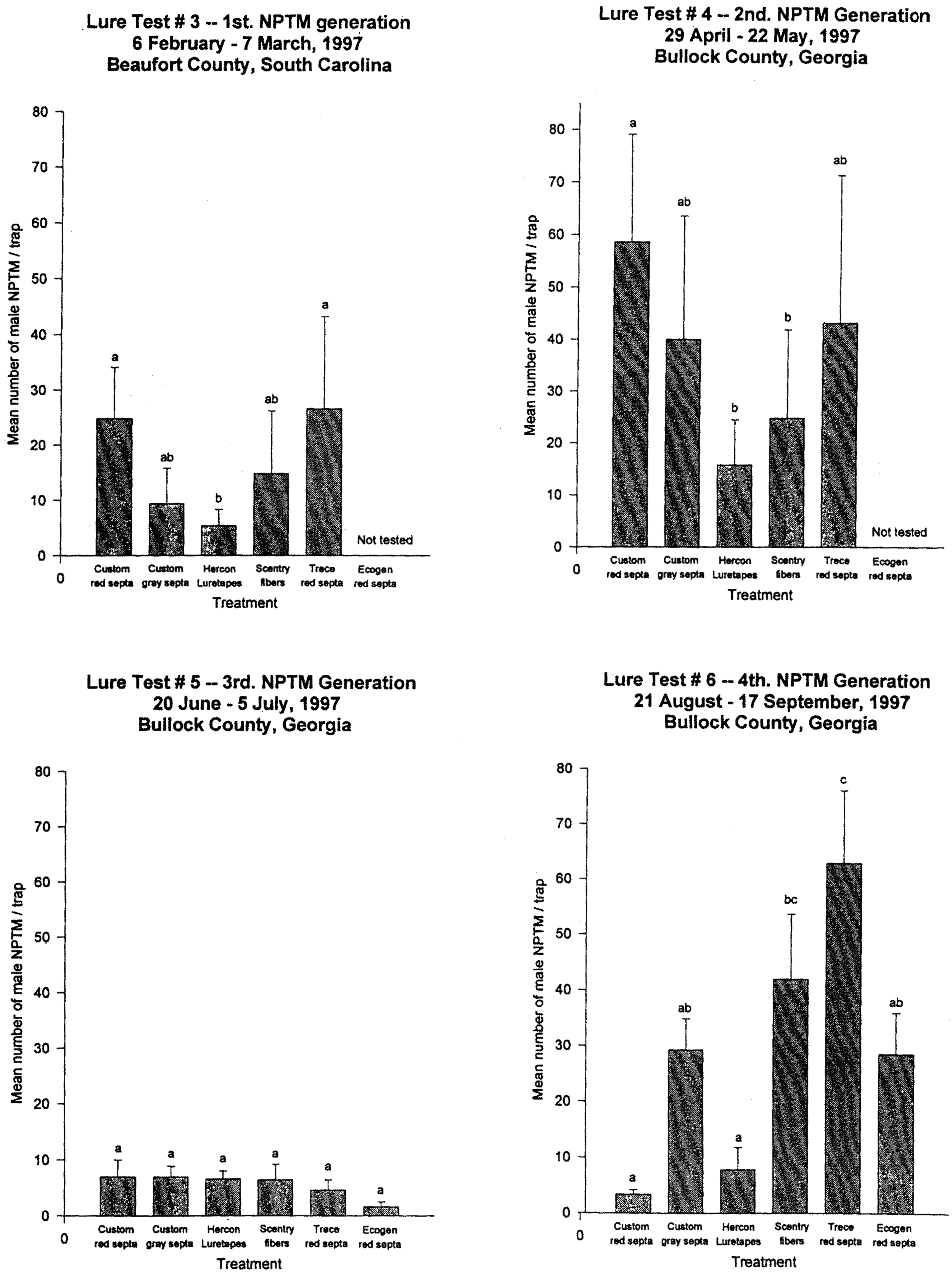

Figure 3—Catches of NPTM males in Pherocon 1C® wing traps baited with custom and commercial lures, South Carolina and Georgia Coastal Plain, 1997.

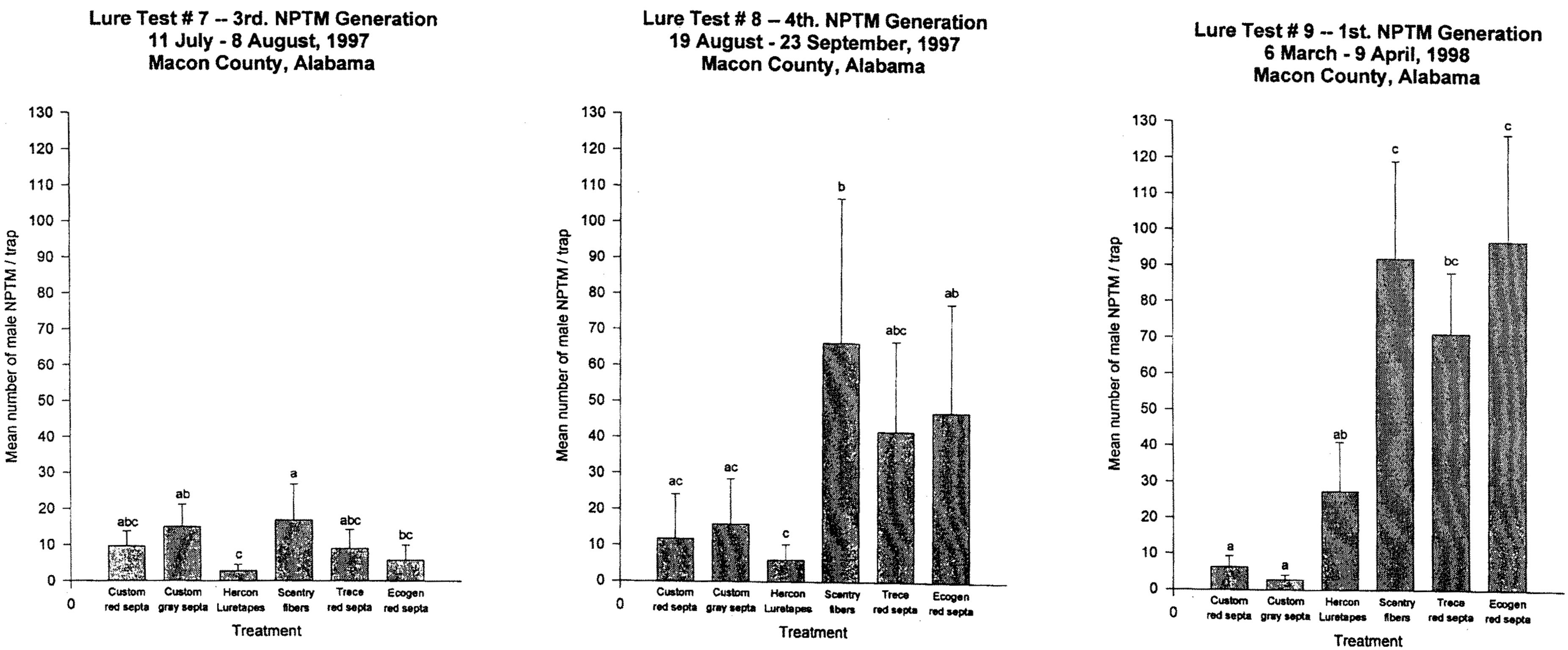

Figure 4—Catches of NPTM males in Pherocon 1C® wing traps baited with custom and commercial lures, southeastern Alabama, 1997–1998.

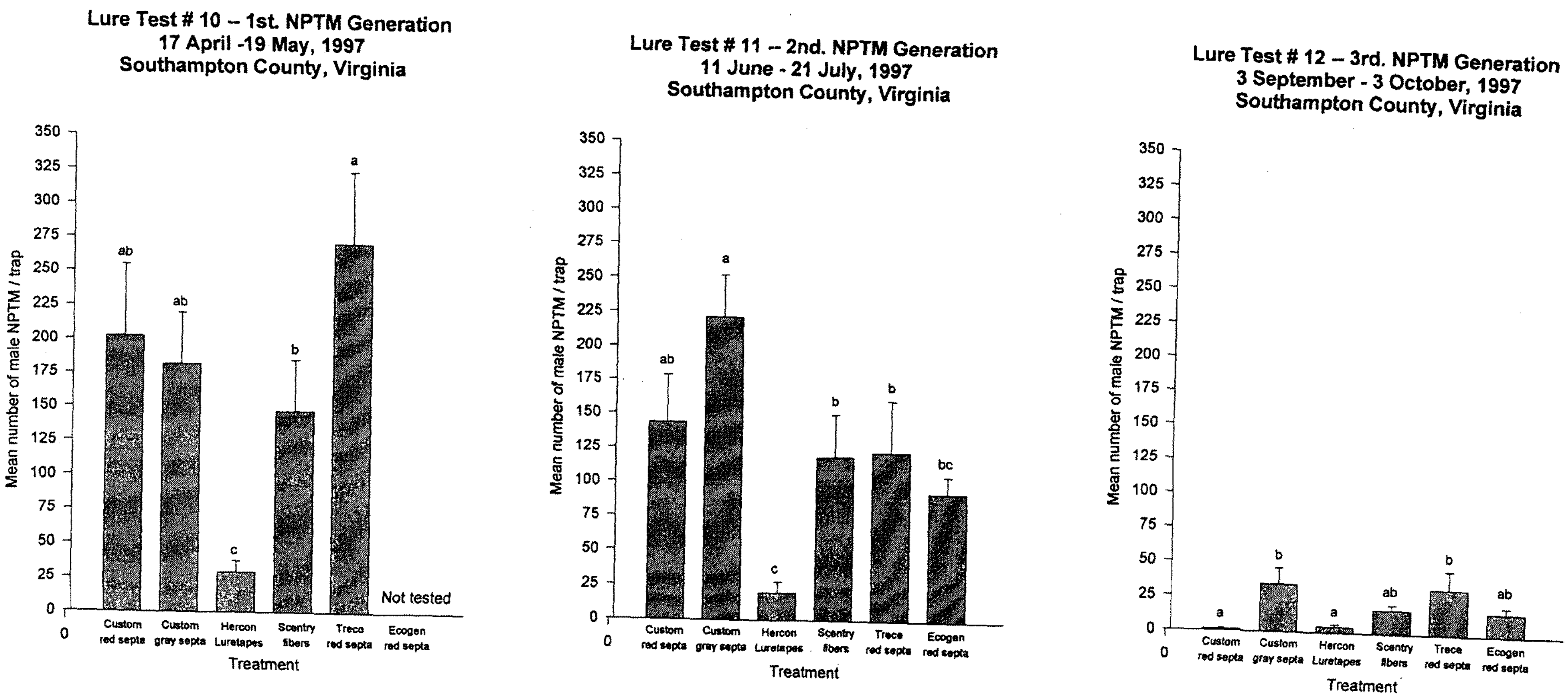

Figure 5—Catches of NPTM males in Pherocon 1C® wing traps baited with custom and commercial lures, southeastern Virginia, 1997.

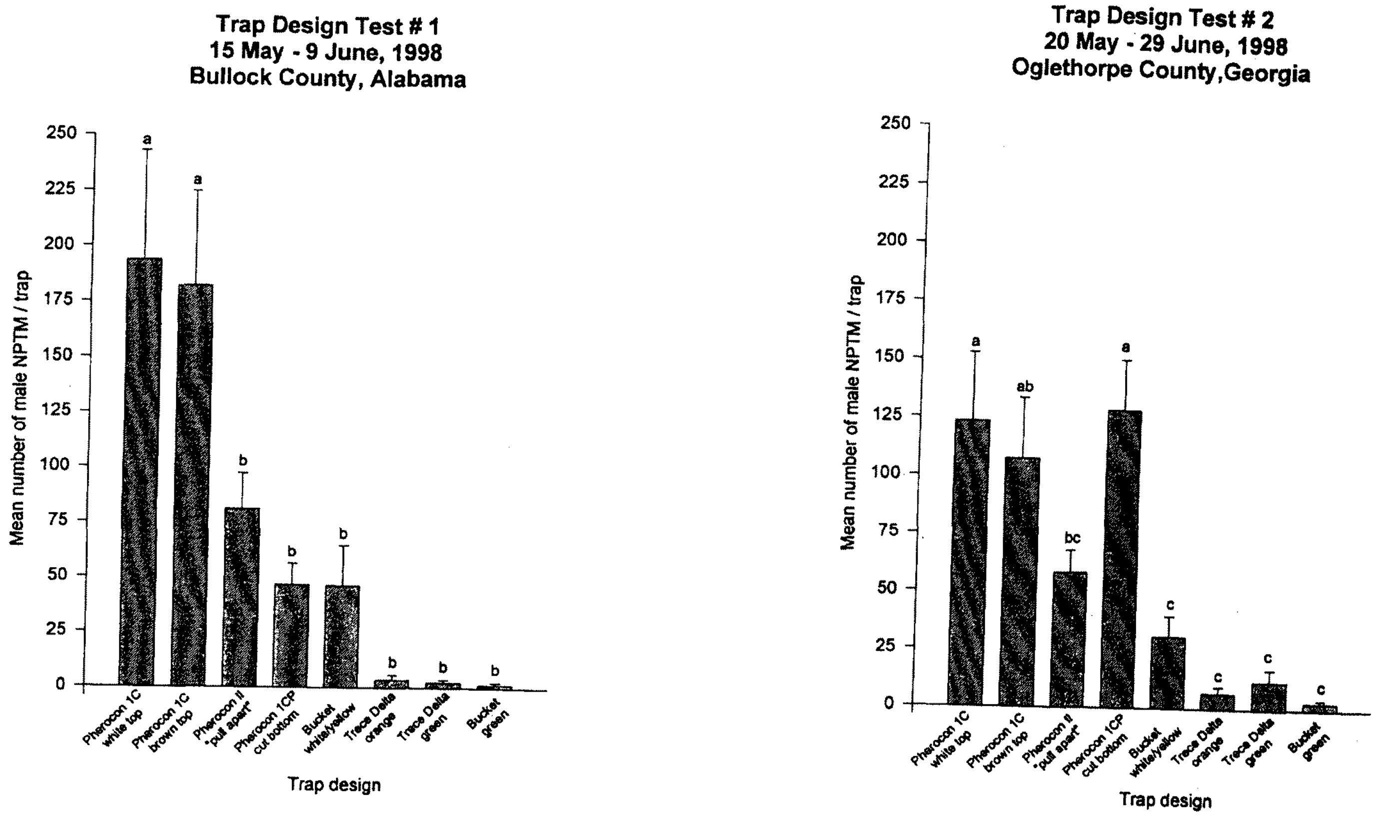

Figure 6—Catches of NPTM males in eight commercial traps baited with Trécé red rubber septa lures, Alabama and Georgia, 1998.

Table 1—Dates for first male NPTM catches ● and dates on which catch equaled or exceeded an average of 1 moth/trap ✱ for eight types of traps baited with Trece red rubber lures, 1998

	Test # 1 — Alabama			Test #2 — Georgia				
Trap type	5/15[a]	5/19	5/22	5/26	5/29	6/01	6/04	6/08
Pherocon 1C - White	●✱	—	—	●✱	—	—	—	—
Pherocon 1C - Brown	●✱	—	—	●✱	—	—	—	—
Pherocon II	●✱	—	—	●✱	—	—	—	—
Pherocon 1CP	●✱	—	—	●✱	—	—	—	—
Delta - Green	—	●✱	—	●	✱	—	—	—
Delta - Orange	—	—	●✱	●✱	—	—	—	—
Bucket- White/yellow	●✱	—	—	●	✱	—	—	—
Bucket - Green	—	●✱	—	—	●	—	—	✱

[a] Traps checked for moths at 3–4 day intervals.

Catches of NPTM males in Pherocon 1 C® wing traps differed significantly among treatments ($F = 3.24$, $P = 0.0138$) with red rubber septa lures containing different ratios of E9-12:OAc : E9,E11-12:OAc. The treatment by trapping period interaction was significant ($F = 1.64$, $P = 0.0216$), but too few moths were caught during each trapping period to examine the relative lure effectiveness over time. Traps with lures containing pheromone ratios of 1:5, 1:10, and 1:20 caught the highest number of moths and did not differ significantly from each other (fig. 9).

DISCUSSION AND CONCLUSIONS

Our tests results have important implications for NPTM pest management. They show that not all NPTM lures or traps

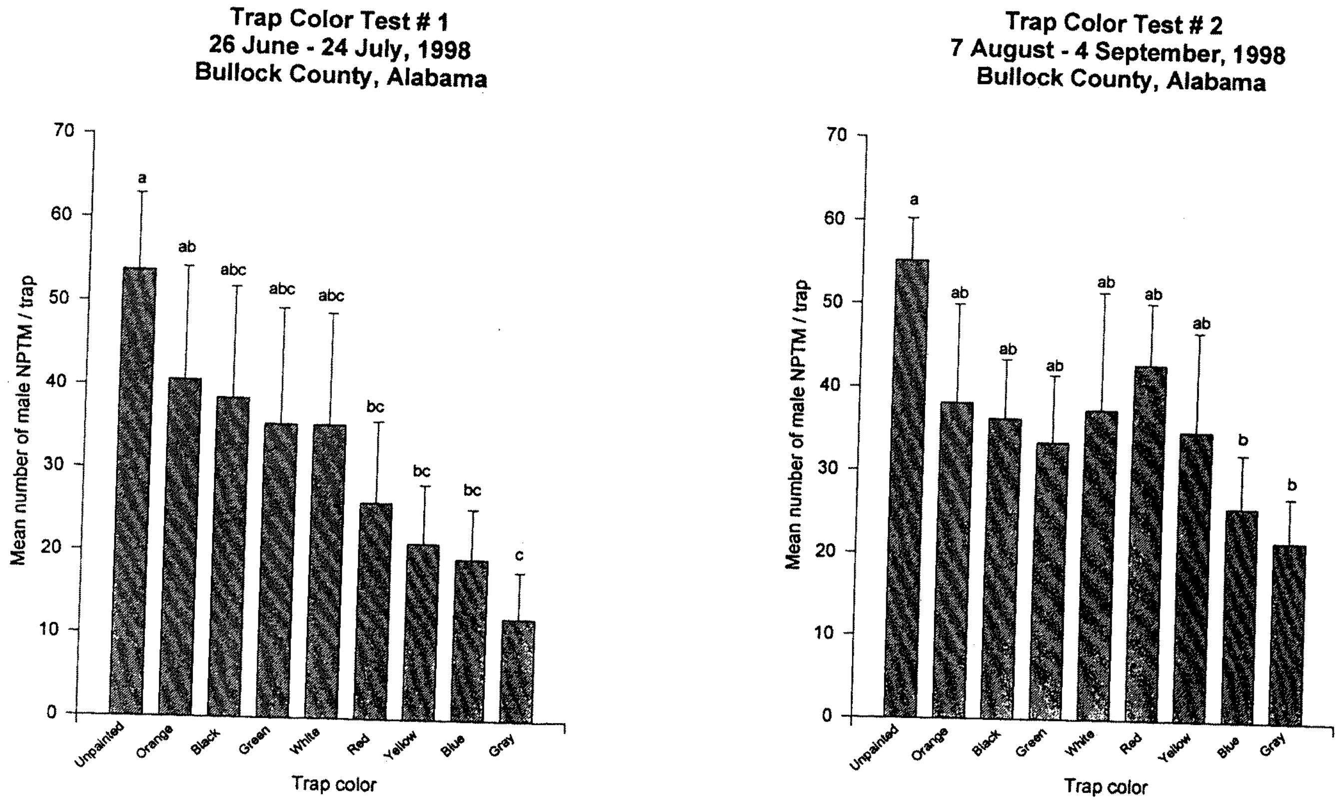

Figure 7—Catches of NPTM males in Pherocon 1C® wing traps painted eight colors and baited with Trécé red rubber septa lures, Alabama, 1998.

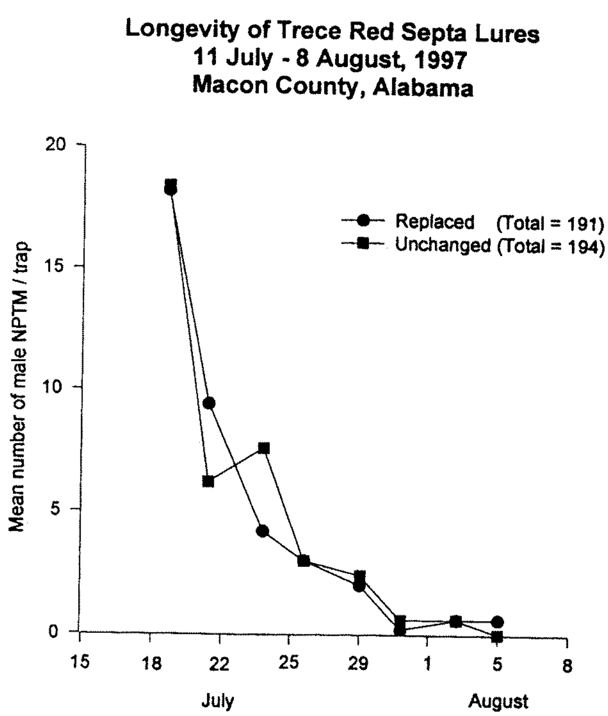

Figure 8—Catches of NPTM males in Pherocon 1C® wing traps baited with Trécé red rubber septa lures changed weekly or unchanged, Alabama, 1998.

are equally effective in attracting male moths. Three important factors which affect the performance of NPTM lures include lure type, dosage, and the *E*9-12:OAc : *E*9,*E*11-12:OAc ratio. Several possible scenarios involving these factors may explain the differences in lure performance and poor summer efficiency of the NPTM traps.

First, both NPTM pheromone components may volatilize and dissipate because of the high ambient temperatures, causing the lures to quickly lose their effectiveness. Lures with higher dosages may be needed during the hot summer and fall months, than in the cooler spring months.

Second, high ambient temperatures in the summer may increase the loss of *E*9-12:OAc on NPTM lures to a rate high enough to inhibit NPTM males. Traps baited with 1 mg of *Z*11-16:OAc lures catch only half as many southern pine coneworm, *D. amatella* moths, as lures with 0.3 or 0.1 mg (Meyer and others 1986).

Third, summer temperatures may cause *E,E*-9,11-12:OAc to rapidly dissipate or degrade, changing the optimum ratio of the two components and eventually leaving only the major compound. Without the minor component, *E*9-12:OAc alone is a weak attractant (Hill and others 1981). Exposure to UV light during the long summer days may also cause isomerization of the diene, *E,E*-9,11-12:OAc, to an inactive isomer, changing the 95:5 ratio of the pheromones. Rapid isomerization of conjugated dienes occurs on red natural rubber septa lures, but it is minimal on gray butyl rubber septa (Brown and McDonough 1986).

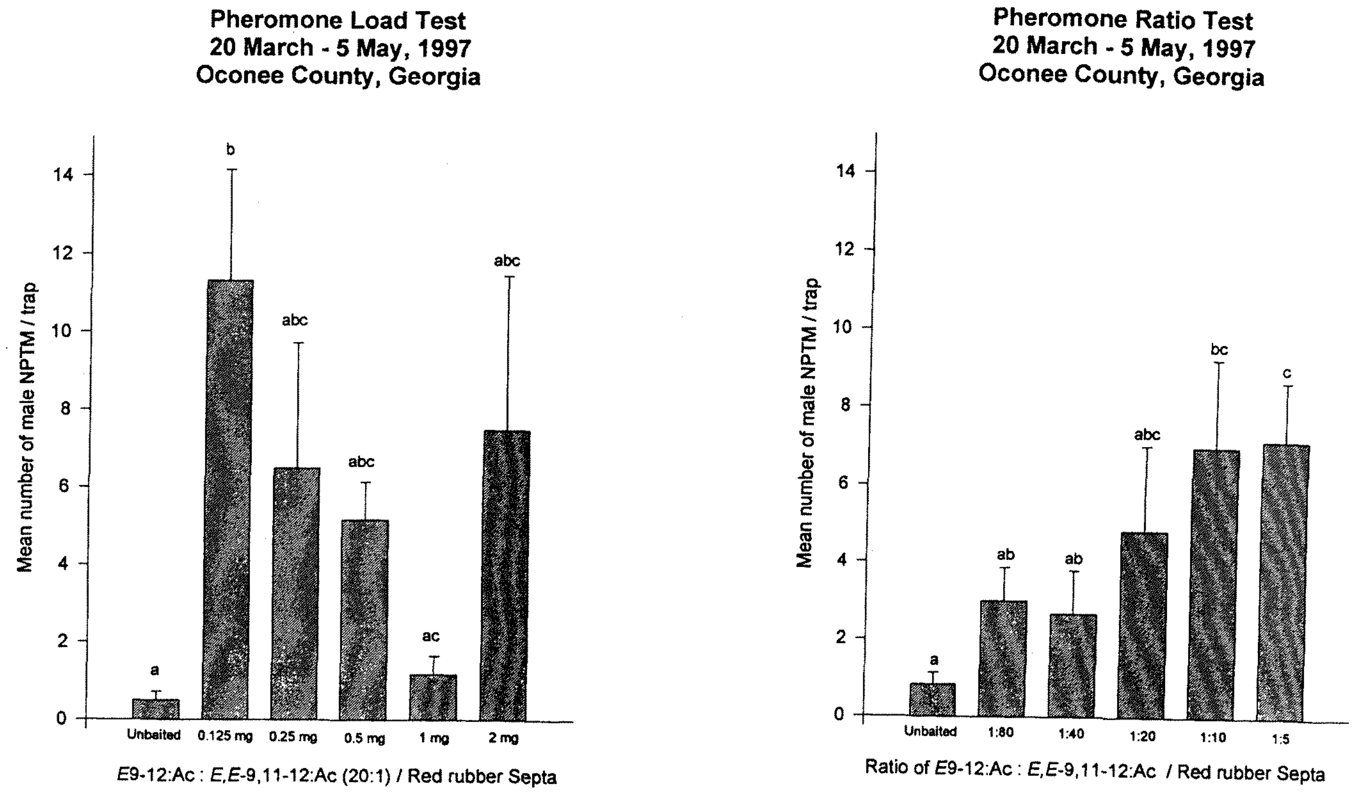

Figure 9—Catches of NPTM males in Pherocon 1C® wing traps baited with custom gray rubber septa lures loaded with different amounts or ratios of pheromones, Georgia, 1997.

Fourth, the optimum ratio of the two synthetic NPTM pheromone components for attracting males may change during the summer months. For example, the omnivorous leafroller moth, *Playnota stultan* (Walsingham), produces the same ratio of its two-component pheromone during three flight periods in May, August and October, but the best pheromone component ratios in lures change for each generation (Baker and others 1978).

Finally, if trap catches of NPTM are low because males have a shorter life span (Asaro and Berisford 2001b) or are less responsive during the summer months than in the spring or because the lures are not competitive with high numbers of feral females, it may be impossible to develop a "better lure" for hot weather conditions.

The traps we tested varied in both the size of the opening through which the moths entered the trap and the area of sticky trap surface. For example, the Pherocon Delta traps® have a smaller opening and less sticky surface than any of the other cardboard sticky traps we tested. In addition, we closed the end panels as indicated in the instructions provided with the trap. Delta traps with the end panels fully open, should be tested again to compare their performance with wing traps. Although trap color influenced trap catch, it may not be as important for NPTM males as for some other insects and commercially available white wing traps appear suitable for NPTM.

Traps or lures with poor efficacy will mislead forest managers or Christmas tree growers about the onset of moth flight and moth population levels. Using the most effective pheromone lure is extremely important when traps are used to detect the first NPTM moths for initiating degree-day models for predicting optimum spray dates. When traps are used to monitor tip moth populations and predict the need for control, consistent performance of lures and traps will be even more important and it will be necessary to adopt a standard lure and trap combination. Our studies suggest that further research to develop a more effective and reliable lure may be warranted.

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REFERENCES

Asaro, C.; Berisford, C. W. 2001a. Predicting infestation levels of the Nantucket pine tip moth (Lepidoptera: Tortricidae) using pheromone traps. Environmental Entomology 30: 776–784.

Asaro, C.; Berisford, C. W. 2001b. Seasonal changes in adult longevity and pupal weight of the Nantucket pine tip moth (Lepidoptera: Tortricidae) with implications for interpreting pheromone trap catch. Environmental Entomology 30: 999–1005.

Baker, J. L.; Hill, A. S.; Roelofs, W. L. 1978. Seasonal variations in pheromone trap catches of male omnivorous leafroller moths, *Platynota stultana*. Environmental Entomology 7: 399–401.

Berisford, C. W. 1974. Comparisons of adult emergence periods and generations of the pine tip moths, *Rhyacionia frustrana* and *R. rigidana*. Annals of the Entomological Society of America 67: 666–668.

Berisford, C. W. 1982. Pheromones of *Rhyacionia* spp.: identification, function and utility. Journal of the Georgia Entomological Society, 2nd. Supplement, p. 23–30.

Berisford, C. W. 1988. The Nantucket pine tip moths. *In:* Berryman, A. A. *Ed.* Dynamics of forest insect populations: patterns, causes, implications. p. 141–161. New York: Plenum Publishing Corp., 603 p.

Berisford, C. W. 1994. Impact of pine tip moth attack on loblolly pine growth: Opportunities for future research. (Unpublished Proposal, 32 p).

Berisford, C. W.; Brady, U. E. 1972. Attraction of Nantucket pine tip moth males to the female sex pheromone. Journal of Economic Entomology 65: 430–433.

Berisford, C. W.; Brady, U. E. 1973. Specificity and inhibition of attraction of male *Rhyacionia frustrana* and *R. rigidana* to their female sex pheromone. Nature 241: 68–69.

Berisford, C. W.; Harman, D. M.; Freeman, B. L. [and others]. 1979. Sex pheromone cross-attraction among four species of pine tip moths, *Rhyacionia* species. Journal of Chemical Ecology 5: 205–210.

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.

Beroza, M. E.; Paszek, C.; Mitchell, E. R. [and others]. 1974. Tests of a 3-layer laminated plastic bait dispenser for controlled emission of attractants from insect traps. Environmental Entomology 6: 926–928.

Brown, D. F.; McDonough, L. M. 1986. Insect sex pheromones: formulations to increase the stability of conjugated dienes. Journal of Economic Entomology 79: 922–927.

Butler, L. I.; McDonough, L. M. 1981. Insect sex pheromones: Evaporation rates of alcohols and acetates from natural rubber septa. Journal of Chemical Ecology 7: 627–632.

Daterman, G. E. 1974. Synthetic sex pheromone for detection survey of European pine shoot moth. USDA Forest Service Research Paper PNW-180 12 p.

Fettig, C. J.; Dalusky, M. J.; Berisford, C. W. 2000. Nantucket pine tip moth phenology and timing of insecticide spray applications in seven southeastern states. USDA Forest Service Research Paper SO-xxx, xx p.

Gargiullo, P. M.; C. W. Berisford; Canalos, C. G. [and others]. 1983. How to time dimethoate sprays against the Nantucket pine tip moth. Georgia Forestry Commission Forest Research Paper No. 44., 11 p.

Gargiullo, P. M.; Berisford, C. W.; Godbee, J. F. 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.

Gargiullo, P. M.; Berisford, C. W.; Canalos, C. G. [and others]. 1984. Mathematical descriptions of *Rhyacionia frustrana* (Lepidoptera: Tortricidae) cumulative catches in pheromone traps, cumulative eggs hatching, and their use in timing of chemical control. Environmental Entomology 13: 1681–1685.

Grant, G. G.; Fogal, W. H.; West, R. J. [and others]. 1989. A sex attractant for the spruce seed moth, *Cydia strobilella* (L.), and the effect of lure dosage and trap height on capture of male moths. The Canadian Entomologist 121: 691–697.

Hill, A. S.; Berisford, C. W.; Brady, U. E. [and others]. 1981. Nantucket pine tip moth, *Rhyacionia frustrana*: identification of two sex pheromone components. Journal of Chemical Ecology 7: 517–528.

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.

Leonhardt, B. A.; Mastro, V. C.; DeVilbiss, E. D. 1992. Evaluation of pheromone dispensers for use in gypsy moth detection (Lepidoptera: Lymantriidae). Journal of Entomological Science 27: 280–284.

McDonough, L. M. 1978. Insect pheromones; Importance and determination of half-life in evaluating formulations. USDA Science and Education Administration, Agricultural Research Service Paper ARS-W-1, 20 p.

Manley, C.; Farrier, M. H. 1969. Attraction of the Nantucket pine tip moth, *Rhyacionia frustrana*, to incandescent light and blacklight, and to virgin females. Annals of the Entomological Society of America 62: 443.

Meyer, W. L.; DeBarr, G. L.; Berisford, C. W. [and others]. 1982. Identification of the sex pheromone of the webbing coneworm moth, *Dioryctria disclusa* (Lepidopera:Pyralidae). Environmental Entomology 11: 986–988.

Meyer, W. L.; DeBarr, G. L.; Hanula, J. L. [and others]. 1986. *Z*-11-Hexadecenyl acetate, a sex pheromone component for the southern pine coneworm, *Dioryctria amatella* (Lepidoptera: Pyralidae). Environmental Entomology 15: 316–320.

Pickering, J.; Ross, D. W.; Berisford, C. W. 1989. An automated system for timing insecticidal sprays for Nantucket pine tip moth control. Southern Journal of Applied Forestry 13: 184–187.

SAS Institute Inc. 1990. SAS/STAT® User's Guide, Version 6. 4th edition. Cary, North Carolina: SAS Institute, Inc. 1686 p.

Smith, R. G.; Daterman, G. E.; Daves, G. D. [and others]. 1974. Sex pheromone of the European pine shoot moth: chemical identification and field tests. Journal of Insect Physiology 20: 661–668.

Webb, J. W.; Berisford, C. W. 1978. Temperature modification of flight and response to pheromones in *Rhyacionia frustrana*. Environmental Entomology 7: 278–280.

Yates, H.O. III. 1960. The Nantucket pine tip moth: A literature review. USDA Forest Service Research Paper SE-115, 19 p.