INVESTIGATION OF ORCHARD USE PARAMETERS FOR THE SEX PHEROMONE OF THE HICKORY SHUCKWORM, *CYDIA CARYANA* (FITCH) IN PECAN PRODUCTION

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IN PECAN PRODUCTION

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PREFACE

Integrated pest management (IPM) systems provide a necessary alternative to calendar driven, prophylactic applications of pesticides. The use of such systems requires that application of such materials, especially insecticides, be based on knowledge of presence and abundance of the target species. The sex pheromone of Cydia caryana (Fitch), the hickory shuckworm, may be of such use to the commercial pecan producer. The present research was undertaken to delineate practical use parameters for integration of the pheromone into existing pecan IPM systems.

To enhance readability and expedite publication, this manuscript has been prepared in publication format. Chapter I (Introduction) advises the reader of the pest species and its biology, the concept of pheromones, and outlines the purposes of the eight investigations undertaken. The eight analyses are subsequently grouped as they will be published. Thus, Chapter II deals with adult emergence patterns, population trends and activity patterns of the species as delineated by pheromone trapping. Chapter III is concerned with trap design and placement under field conditions and Chapter IV with the relationship of pheromone trap capture to fruit infestation. Each of these chapters is presented with an introduction, materials and methods, results and discussion, and a bibliography. Chapter V presents a discussion of some research implications of the previously discussed analyses and contains a bibliography.

The author wishes to express his sincere gratitude to everyone who assisted with and cooperated in this research effort. Without the support and dedication of many, this project would never have reached fruition. I am especially indebted to Dr. Ray Eikenbary, Regents Professor, Dept. of Entomology, who served as my major advisor but more importantly, as my close friend and colleague for many years. His support and expertise were invaluable to this project and, I am sure, will continue to be in the future.

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NOMENCLATURE

ANOVA	analysis of variance
ca	circa, approximately
ha	hectare
IPM	integrated pest management
km	kilometer
LSD	least significant difference
m	meter
mm	millimeter
P	level of probability
R^2	correlation coefficient squared
SE	standard error

CHAPTER I

INTRODUCTION

The hickory shuckworm, *Cydia caryana* (Fitch) (Lepidoptera: Tortricidae: Olethreutinae) is a key pest of pecan, *Carya illinoensis* (Wang), throughout the major production areas of the United States (Osburn et al., 1963; Payne et al., 1979). Although damage assessment is difficult, losses due to actual damage and control costs combined have been estimated to be as high as $11.3 million annually in Georgia (Suber and Todd, 1980).

A native species, *C. caryana* is generally distributed throughout the pecan belt from Texas eastward (Walker, 1928; Osburn et al., 1963; Payne et al., 1979). Two to five generations occur annually depending on the local climate. In the lower South, four to five are common. Passing the winter as fully developed larvae in pecan shucks on the orchard floor, the insects pupate in late winter and early spring. First emergence may occur by mid-February with peak emergence reported in April (Van Duyn, 1967; Tedders and Gentry, 1970; Harris et al., 1975; McVay and Estes, 1989). Calcote and Hyder (1980) and Calcote (1989) have reported that emergence of adults from overwintering sites in shucks is bimodal. Emergence peaks were found to occur in both spring and summer with the smaller, summer peak coinciding with the time of greatest direct damage attributable to the species. Eggs of the spring brood are characteristically deposited on the foliage and fruit of hickory. Oviposition occurs to a lesser extent on pecan foliage and phylloxera galls on both pecan and hickory (Moznette, 1938, 1941; Boethel et al., 1974). The greater proportion of spring adults oviposit on native hickories which set fruit 2 to 3 weeks earlier than does pecan (Moznette 1938, 1941). This has been termed a "suicide" generation by some, however enough progeny survive to insure increasing populations for each succeeding generation (Payne et al., 1979).

Adult females of succeeding generations, once mated, oviposit on pecan fruit and foliage. Hatching larvae bore directly into the shuck. If the fruit is infested prior to hardening of the shell, the larvae bore into the interior to feed, causing the fruit to abort (Smith, 1985; McVay and Estes, 1989). In years of light fruit set, crop loss has been estimated to be as high as fifty percent or more (Osburn et al., 1963; Phillips et al., 1964; Smith et al., 1973). Once the pecan shells have hardened and are impenetrable to the larvae, newly hatched individuals feed by mining within the shuck (Payne et al., 1979; Calcote et al., 1984; McVay and Estes, 1989). Several types of damage can result from this feeding behavior: delayed maturation, improper kernel development as a result of feeding damage to the vascular bundles of the shuck, scarring of the shell, discoloration of the shell and abnormal adherence of the shuck to the mature pecan which creates processing problems (Gill, 1924; Adair, 1930; Moznette et al., 1931; Walker, 1933; Moznette, 1941; Todd, 1967; Tedders and Edwards, 1972; Payne and Heaton, 1975; Calcote et al., 1984).

Due to the difficulty of post-ovipositional control of immature forms, most integrated pest management (IPM) program efforts that include C. caryana have encouraged monitoring of adult populations (McVay and Ellis, 1979; Ellis et al., 1983; McVay and Strother, 1983). Such monitoring efforts have relied principally on the use of blacklight traps. Producer acceptance of blacklight monitoring methodology has been limited (Ellis et al., 1983; Smith, 1985). Control tactics, therefore, depend greatly on the application of preventative insecticide sprays based on nut phenology and the timing of damaging shuckworm generations (Neel, 1959; Osburn and Tedders, 1969; Payne and Heaton, 1975; Ellis and Polles, 1976; Ring et al., 1987; Calcote, 1989). Such control tactics are considered unacceptable for pecan IPM programs as damage has only been qualitatively determined and actual need for chemical treatment is not determined prior to application.

Semiochemicals, also referred to as behavior modifying chemicals, may provide alternatives for monitoring and/or suppression of C. caryana. Among semiochemicals, pheromones are the most often used in IPM program efforts. The term pheromone is taken from the Greek pherin (to carry) and hormon (to excite or stimulate) and is applied to those semiochemicals which mediate communication between individuals of the same species (Karlson and Butenandt, 1959; Karlson and Luscher, 1959). Pheromones can be categorized as releasers (triggering an immediate and reversible behavioral change in the recipient) or as primers (inducing delayed, lasting response).

Most often studied and documented as management tools are the sex pheromones which are releasers that are used to increase the probability of successful mating (Jutsum and Gordon, 1989). Either females or males may produce the pheromone or both sexes may contribute to the communication involved in mating (Smith, 1985), although in the majority of documented cases the female is the emitter. Sensory receptors on the antennae of receiving individuals detect the pheromone and a behavioral response follows which may be simple or complex. Ultimately, the sexes are brought together for copulation.

Sex pheromones and parapheromones of hundreds of lepidopterous species have been identified since the sex pheromone of *Bombyx mori*, the silkworm moth, was identified over thirty years ago (Butenandt et al., 1959). Many of those identified and subsequently synthesized commercially are utilized in IPM programs of different types. In conjunction with easy-to-use traps of various types, sex pheromones provide a means of detecting of insect species. This can provide early warning of pest incidence, be used as a survey tool for defining distribution and area of infestation, or for quarantine inspections. In conjunction with treatment thresholds, the pheromone can be useful in the timing of treatments and other sampling methods and for risk assessment. Thirdly, pheromone trapping can be a valuable tool for density estimation by providing information on population trends, dispersion and risk assessment and the effects of control measures (Wall, 1989; Mitchell, 1981). Additionally, some success has been achieved in the reduction of insect damage and/or infestation levels when target areas are saturated with the sex pheromone for the purpose of mating disruption (Metcalf and Metcalf, 1982; Younce, 1980; Rothchild, 1981; Campion et al., 1989). Anderson et al. (1973) concluded that C. caryana females produce a sex pheromone but no further work was reported in this context until 1985. Then, Smith (1985), Smith et al. (1987) and McDonough et al. (1990) reported on the identification and synthesis of the pheromone and the development of an effective field lure. The lure was identified as a 100:0.6 blend of (E,E)-8,10-dodecadien-1-ol acetate and (E,Z)-8,10-dodecadien-1-ol acetate. Field testing proved the effectivness of the blend as a lure but did not evaluate the pheromone's usefulness in an IPM program. Therefore the objectives of the present research are as follows:

1. Determination of some of the flight habits and emergence patterns of C. caryana in commercial pecan orchards utilizing the sex pheromone.

2. Determination of field use parameters for deployment of C. caryana sex pheromone baited traps as an integral part of established pecan IPM programs. Parameters investigated include (a) trap type; (b) trap height; (c) horizontal placement of traps within the tree canopy; and (d) the effects of cardinal direction on trap placement.
3. Determination of the relationships between the numbers of male C. caryana captured and the actual infestation of fruit in the tree. This is one of the first steps in development of an economic treatment threshold.

It is beyond the purpose of this dissertation of give a complete review of the state of knowledge concerning sex pheromone communication in insects and its use in IPM. Pertinent literature concerning techniques relevant to the results will be cited. For a more complete review of sex pheromones and their use, refer to: Jacobsen (1972), Birch (1974), Young and Silverstein (1975), Shorey and McKelvey (1977), Brand et al. (1979), Ritter (1979), Carde (1979), Roelofs (1980), Mitchell (1981), Kydonieus and Beroza (1982), Tamaki (1985) and Jutsum and Gordon (1989).

Literature Cited

Adair, H. S. 1930. The hickory or pecan shuckworm. Miss. State Plant Board 9(4): 1-3.

Anderson, A. L., H. W. VanCleave, and T. L. Payne. 1973. An investigation of a sex pheromone of the hickory shuckworm, Laspeyresia caryana (Fitch). Folia. Entomol. Mex. 25-6.

Birch, M. C. 1974. Pheromones. American Elsevier, New York. 495 pp.

Boethel, D. J., J. T. Criswell, and R. D. Eikenbary. 1974. Incidence of hickory shuckworm in galls of Phylloxera spp. on pecan. J. Econ. Entomol. 67: 692-3.

Brand, J. M., J. C. Young, and R. M. Silverstein. 1979. Insect pheromones: a critical review of recent advances in their chemistry, biology and application. Fortschr. Chem. Org. Naturst. 37: 1-190.

Butenandt, A., R. Beckman, D. Stamm, and E. Hecker. 1959. Uber den Sexuallockstoff des Seidenspinner Bombyx mori, Reidarstellung und Konstitution. z. Naturforsch. B14, 283-4.

Calcote, V. R. 1989. Seasonal occurrence of the hickory shuckworm in pecan. Proc. S. E. Pecan Growers Assoc. 82: 55-62.

Calcote, V. R., and D. E. Hyder. 1980. Late season emergence of shuckworm from overwintering shucks. Proc. S. E. Pecan Growers Assoc. 73: 75-7.

Calcote, V. R., R. E. Hunter, and T. E. Thompson. 1984. Nutrient flow through the pecan shuck into the nut and disruption of this flow by hickory shuckworm larvae. Proc. S. E. Pecan Growers Assoc. 77: 61-9.

Campion, D. G., B. R. Critchley, and L. J. McVeigh. 1989. Mating disruption, pp. 89-119. In A. R. Jutsum and R. F. S. Gordon [eds.], Insect Pheromones in Plant Protection. John Wiley & Sons, New York.

Carde, R. T. 1979. Behavioral responses of moths to female-produced pheromones and the utilization of attractant-baited traps for population monitoring, pp. 286-315. In R. Rabb and G. Kennedy [eds.], Movement of Highly Mobile Insects: Concepts and Methodology in Research. North Carolina University, Raleigh.

Ellis, H. C. and S. C. Polles. 1976. Aerial application for control of certain pecan insects. Proc. S. E. Pecan Growers Assoc. 69: 119-21.

Ellis, H. C., P. Bertrand, M. French, and C. Bruce. 1983. Pecan pest management in Georgia, pp. 89-100. In J. A. Payne [ed.], Pecan Pest Management - Are We There? Misc. Pub. Entomol. Soc. of Am. 13(2).

Gill, J. B. 1924. Important pecan insects and their control. USDA Farmers Bull. 1364: 7-11.

Harris, E. D., Jr., N. E. McGlohon, and H. C. Ellis. 1975. Pecan insects and diseases and their control. Ga. Ext. Bull. 644, Univ. of Ga., Athens. 20 pp.

Jacobsen, M. 1972. Insect Sex Pheromones. Academic Press, New York. 382 pp.

Jutsum, A. R., and R. F. S. Gordon [eds.]. 1989. Insect Pheromones in Plant Protection. John Wiley & Sons, New York. 369 pp.

Karlson, P., and A. Butenandt. 1959. Pheromones (ectohoromones) in insects. Ann. Rev. Entomol. 4: 49-58.

Karlson, P., and M. Luscher. 1959. 'Pheromones' a new term for a class of biologically active substances. Nature 183: 55-6.

Kydonieus, A. F., and M. Beroza [eds.]. 1982. Insect Suppression with Controlled Release Pheromone Systems, Vol. I and II. CRC Press. 274 pp. (Vol. I), 312 pp. Vol. II).

McDonough, L. M., R. D. Eikenbary, M. T. Smith, H. G. Davis, C. L. Smithhisler, G. A. Hedger, R. K. Campbell, J. A. Payne, W. Reid, and J. R. McVay. 1990. Sex pheromone of hickory shuckworm, Cydia caryana; development of an effective fieldlure. J. Chem. Ecol. 16(2): 317-24.

McVay, J. R., and H. C. Ellis. 1979. Extension approaches to pecan pest management in Alabama and Georgia, pp. 121-49. In D. J. Boethel and R. D. Eikenbary [eds.], Pest Management Programs for Deciduous Tree Fruits and Nuts. Plenum Press, New York.

McVay, J. R., and G. R. Strother. 1983. Evolution and status of pecan pest management in Alabama, pp. 101-10. In J. A. Payne [ed.], Pecan Pest Management - Are We There? Misc. Pub. Entomol. Soc. Am. 13(2).

McVay, J. R., and P. M. Estes. 1989. Insect and mite pests, pp. 105-25. In W. D. Goff, J. R. McVay, and W..Gazaway [eds.], Pecan Production in the Southeast: a guide for growers. Ala. Coop. Ext. Ser. Pub. ANR-459, Auburn Univ.

Metcalf, R. A., and R. A. Metcalf. 1982. Attractants, repellents, and genetic control in pest management, pp. 279-314. In R. L. Metcalf and W. H. Luckman [eds.], Introduction to Insect Pest Management, 2nd Ed. John Wiley & Sons, New York.

Mitchell, E. R. [ed.]. 1981. Management of Insect Pests with Semiochemicals. Plenum Press, New York. 514 pp.

Moznette, G. F. 1938. Some important biological factors in the control of the hickory shuckworm on pecan. Proc. S. E. Pecan Growers Assoc. 32: 11-4.

Moznette, G. F. 1941. Progress in the control of the hickory shuckworm of pecan. Proc. S. E. Pecan Growers Assoc. 34: 42-8.

Moznette, G. F., T. L. Bissel, and H. A. Adair. 1931. Insects of the pecan and how to combat them. USDA Farmers Bull. 1954. 59 pp.

Neel, W. W. 1959. Shuckworm control tests in Mississippi during 1957-1959, with special reference to foliage sprays and granular insecticides. Proc. S. E. Pecan Growers Assoc. 52: 83-7.

Osburn, M. R., W. C. Pierce, A. M. Phillips, J. R. Cole, and G. L. Barnes. 1963. Controlling insects and diseases of the pecan. USDA Agric. Handb. No. 240, 55 pp.

Osburn, M. R., and W. L. Tedders. 1969. Insecticides for control of the hickory shuckworm on pecan. J. Ga. Entomol. Soc. 4(4): 178-80.

Payne, J. A., and E. K. Heaton. 1975. The hickory shuckworm: its biology, effect on nut quality, and control. Annu. Rep. Northern Nut Growers Assoc. 66: 19-25.

Payne, J. A., H. L. Malstrom, and G. E. KenKnight. 1979. Insect pests and diseases of the pecan. USDA SEA Agric. Manual No. ARM-S-5, 43 pp.

Phillips, A. M., J. R. Large, and J. R. Cole. 1964. Insects and diseases of the pecan in Florida. Bull. 619A, Univ. of Fla. Agric. Exp. Sta., Gainesville. 87 pp.

Ring, D. R., J. A. Payne, and J. W. Snow. 1987. An integrated pest management program for pecans in Georgia: second year. Proc. S. E. Pecan Growers Assoc. 80: 79-84.

Ritter, F. J. 1979. Chemical Ecology: Odour Communication in Animals. Elsevier, North Holland, Amsterdam. 427 pp.

Roelofs, W. L. 1980. Pheromones and their chemistry, pp. 583-602. In M. Locke and D. S. Smith [eds.], Insect Biology in the Future. Academic Press, New York.

Rothschild, G. H. L. 1981. Mating disruption of lepidopterous pests: current status and future prospects, pp. 207-28. In E. R. Mitchell [ed.], Management of Insect Pests with Semiochemicals. Plenum Press, New York. 514 pp.

Shorey, H. H., and J. J. McKelvey, Jr. [eds.]. 1977. Chemical Control of Insect Behavior: Theory and Application. John Wiley & Sons, New York. 414 pp.

Smith, J. S., Jr., W. L. Tedders, and C. R. Gentry. 1973. Blacklight trapping of the hickory shuckworm moth in Georgia pecan orchards. Trans. Am. Soc. Agric. Eng. 16(1): 127-8.

Smith, M. T. 1985. Characterization of the hickory shuckworm, Cydia caryana (lepidoptera: tortricidae: olethreutinae), sex pheromone: Electrophysiological, behavioral, chemical and field analysis. Ph.D. dissertation, Okla. St. Univ. 137 pp.

Smith, M. T., L. M. McDonough, S. Voerman, H. G. Davis, R. D.Eikenbary, and C. L. Smithhisler. 1987. Hickory shuckworm Cydia caryana (lepidoptera: tortricidae: olethreutinae): electroantennogram and flight tunnel studies of potential sex pheromone components. Entomol. Exp. Appl. 44: 23-30.

Suber, E. F., and J. W. Todd [eds.]. 1980. Summary of economic losses due to insect damage and costs of control in Georgia 1970-1976. Univ. of Ga. Special Publ. No. 7.

Tamaki, Y. 1985. Sex pheromones, pp. 145-191. In G. A. Kerkut and L. I. Gilbert [eds.], Comprehensive Insect Physiology, Biochemistry, and Pharmacology: Behavior, Vol. 9. Pergamon Press, Oxford.

Tedders, W. L., and G. W. Edwards. 1972. Effects of blacklight trap design and placement on catch of adult hickory shuckworm. J. Econ. Entomol. 65: 1624-7.

Tedders, W. L., and C. R. Gentry. 1970. Know these pecan enemies -- hickory shuckworm and pecan weevil. Progressive Farmer, Aug., 1970, p. 26.

Todd, L. 1967. A spring emergence study of the hickory shuckworm, Laspyresia caryana. Tex. Pecan Growers Assoc. Proc. 46: 80-5.

Van Duyn, J. W. 1967. Emergence of overwintering shuckworm in north Florida. Proc. S. E. Pecan Growers Assoc. 60: 45-6.

Walker, F. W. 1928. The shuckworm, a serious pest of the pecan in Florida. Proc. Ga.-Fla. Pecan Growers Assoc. 211: 26-31.

Walker, F. W. 1933. The pecan shuckworm. Bull. 258, Univ. of Fla. Agric. Exp. Sta., Gainesville. 18 pp.

Wall, C. 1989. Monitoring and spray timing, pp. 39-66. In A. R. Jutsum and R. F. S. Gordon [eds.], Insect Pheromones in Plant Protection. John Wiley & Sons, New York.

Younce, C. E. 1980. Mating disruption of the lesser peachtree borer, Synanthedon pictipes (Grote and Robinson), and the peachtree borer, S. exitiosa (Say), with a hollow fiber formulation, pp. 21-30. In D. T. Johnson [ed.], Tree Fruit and Nut Pest Management in the Southeastern United States. Misc. Pub. Entomol. Soc. Am. 12(2).

Young, J. C., and R. M. Silverstein. 1975. Biological and chemical methodology in the study of insect communication systems, pp. 75-161. In D. G. Moulton, A. Turk, and J. W. Johnson, Jr. [eds.], Methods in Olfactory Research. Academic press, New York.

CHAPTER II

ADULT EMERGENCE PATTERNS,
POPULATION TRENDS AND
ACTIVITY PATTERNS OF
Cydia caryana

Introduction

The emergence pattern of adult _C. caryana_ from their larval overwintering sites in shucks has been reported by several investigators (Moznette, 1938; Phillips et al., 1960; Osburn et al., 1966; Todd, 1967; Van Duyn, 1967; Tedders and Gentry, 1970; Harris et al., 1975; Calcote and Hyder, 1980; Calcote, 1989). Most indicate that spring emergence begins as early as February and usually not later than mid-March, with peak emergence occurring during the month of April. Evidently, it was assumed that emergence of this brood ceased in early summer by most early investigators, although Phillips et al. (1960) reported that moths of this brood may continue to emerge throughout the summer. Todd (1967) reported two emergence peaks from shucks collected from Louisiana (April 4-18 and May 9-23) and one (April 4-18) in Texas. Calcote and Hyder (1980) and Calcote

(1989) monitored emergence season-long in west Texas and discovered a second, relatively low, period of emergence during the period, July-September. These are the only reports of a bimodal emergence pattern of adults of the overwintering brood. The first study reported here was designed to monitor the seasonal emergence of this brood in Alabama to determine if the bimodal pattern occurs in the Southeast as well.

Population trends of adult C. caryana have been investigated by monitoring emergence from shucks and infested fruit as mentioned above and post-activity information has been obtained through inspection of fruit both abcissed and on the tree (Moznette, 1938; Phillips et al., 1960; Osburn et al., 1966; Van Duyn, 1967; Boethel et al., 1974; Ellis et al., 1983; McVay and Estes, 1989; Payne and Heaton, 1975). Blacklight traps have seen limited use, both experimentally and commercially, as tools for determining adult population trends for almost 30 years (Tedders and Osburn, 1966; Tedders and Edwards, 1970; Tedders and Edwards, 1972; Tedders et al., 1972; Smith et al., 1973; Gentry et al., 1975; McVay et al., 1978; Smith and Tedders, 1978; McVay and Ellis, 1979). Although such traps can be effective monitoring devices, their utility is limited in a practical, grower oriented program (Tedders and Osburn, 1967). The second study reported in this chapter determined adult population trends of C. caryana through the use of sex pheromone baited traps with some comparison of results with those developed with blacklight technology.

Although C. caryana has been described as a nocturnal species for many years (Moznette, 1938), the only available information concerning flight period activity during the hours of darkness was published by Tedders and Edwards (1970). They found the species to be somewhat active throughout the hours of darkness but to tend a little toward the crepuscular. Most activity occurred during the first 2 to 3 hours following sunset with another minor peak of activity at the 8 to 10 hour point (1 to 2 hours prior to sunrise). The third study reported here involved the delineation of the nocturnal activity patterns of C. caryana on the basis of the capture of adult males in sex pheromone baited wing traps.

Materials and Methods

Emergence Patterns from Overwintering Sites

Pecan shucks were collected from Stuart pecan orchards in Baldwin, Bullock and Covington Counties, Alabama during the first week of December, 1988. All three orchards were known to be infested by the hickory shuckworm. At each location, two burlap bags normally used for pecan storage were filled with ca. 12 kg of pecan shucks and transported to Auburn, AL. Shucks were then transferred to 9 galvanized No. 3 wash tubs (three for shucks from each location) 0.61 m in diameter and 279.4 mm in depth. A series of 10 holes ca. 3.2 mm in diameter was drilled into the bottom of each tub prior to placement of shucks for drainage. Each tub was then placed on 3 baked clay bricks to maintain them 101.6 mm above the soil surface and filled to within 50.8 mm of the top with shucks (shuck depth ca. 228.6 mm). Shucks were placed loosely into the containers to approximate the consistency of post-harvest shuck piles normally found in pecan orchards. Each tub was then securely covered with fine mesh hardware cloth to prevent escape of emerging adults. Access ports were cut into the hardware cloth to facilitate removal of insects. The ports were wired shut except for those times when C. caryana adults were removed. The containers were maintained in a screen house until March 1, 1989 and were checked regularly for adult emergence.

On March 1, the tubs were removed, with supports, to an area under the canopy of a large pecan tree. Adult emergence was monitored three times weekly from March 1 until Sept. 29, 1989. Emerging adults were counted and removed at each recording period. No attempt was made to determine the sex of the adults.

Seasonal Population Trends

Seasonal population trends for adult male hickory shuckworms were determined from captures made with pheromone traps baited with a commercial preparation of the species' sex pheromone. Five traps were located in an orchard of mature pecan trees in Mobile County, AL., as part of a trap type study and 14 were located in a similar orchard in

Baldwin Co. in which a vertical distribution study was being conducted. Both studies are discussed in Chapter III. All traps were placed in mature orchards (65 - 75 yr old) that were predominately composed of the Stuart variety. In both cases, trees were planted on 18.2 m (60 ft) centers and selection of data trees was based on the following criteria: [1] Stuart variety, [2] healthy tree with no visible mechanical or other damage, [3] additional trees of the same variety were located on each directional facing from the data tree, [4] no data tree was to be located on the orchard perimeter, and [5] data trees were separated by at least two non-data trees (54.6 m). In the Mobile Co. orchard, all traps were located 9.1 m (30 ft) above the orchard floor on the west side of the tree near the vertical center of the canopy. At the Baldwin Co. location, seven traps were situated 9.1 m above the orchard floor and seven were located 4.57 m (15 ft) above the floor. Traps were situated on the west facing near the vertical center of the canopy. Pherocon Ic, "wing type", traps were used at both locations. Traps were suspended in the tree canopies with a rope and pulley arrangement. Pulleys were affixed to limbs at the desired height and location and traps were raised and lowered on 3.18 mm (1/8 in) nylon cordage. Traps were installed and charged with bait on May 2, 1989 and March 6, 1990 in Mobile Co. and in Baldwin Co. on April 25, 1989 and March 20, 1990. The sex pheromone lure used was a commercial preparation marketed by Scentry, Inc. of Buckeye, AZ. and consisted of grey rubber septa charged with 50 micrograms of attractant blend. The traps were monitored at 7-day intervals throughout the entire season in 1989 (ca. Oct. 30) and until early June in 1990. The number of males captured was recorded on each visit and all insects removed from the trap. Lures and trap bottoms were replaced every 28 days to insure optimum performance. Old lures and trap bottoms were removed from the orchards.

Nocturnal Activity Patterns

In 1989, six sex pheromone baited Pherocon Ic traps were monitored for adult males during periods of heavy shuckworm activity as indicated by traps involved in other studies. Three of the traps were located in a Mobile Co., AL, orchard and three in a similar orchard in Baldwin Co. Both orchards consisted of mature trees, 60 to 70 yr. old. Data trees were randomly selected by the same criteria described in the previous study. Traps were suspended 9.1 m above the orchard floor near the vertical center of the canopy on the west side of the tree. Installation was as previously described. The pheromone lure obtained from Scentry, Inc. was used throughout the study. Traps were installed on May 2, 1989. Fresh lures and trap bottoms were installed every 28 days. Once indications of heavy shuckworm activity were detected, each of the three traps at each location was monitored on an hourly basis throughout darkness. The traps were lowered and cleaned of insects prior to sunset and re-suspended. Beginning 1 hour after sunset, each trap was lowered, the total capture was recorded, captured insects removed and the trap was repositioned. The procedure required ca. 2 min. per trap and was continued until 12 hours after sunset with the last reading occurring ca. 1 hour after sunrise the following morning. Traps at each location were monitored in this manner on Sept. 9, 25 and Oct. 9, 1989, in Mobile Co. and May 15, Sept. 18 and Oct. 19, 1989 in Baldwin Co.

In 1990, only the Mobile Co. location was monitored. Traps were installed on March 6, 1990 and nocturnal activity was monitored on March 26, April 4, April 18 and May 2. The same data trees were utilized in 1989 and in 1990. All other aspects were identical in both years except that in 1990 the study was terminated following the May 2 monitoring.

Results and Discussion

Emergence Patterns from Overwintering Sites

A total of 1,368 *C. caryana* adults emerged from the shucks collected in the fall of 1988 and monitored throughout 1989. The three containers of shucks from the Baldwin Co. location produced 587 adults while 528 and 253 emerged from the Bullock and Covington Co. shucks, respectively. First emergence occurred on March 1 from the Baldwin and Bullock Co. samples and on March 8 from those collected in Covington

Co. The final moth emerged from Covington Co. shucks on Sept. 11, from Bullock Co. samples on Sept. 25 and from those collected in Baldwin Co. on Sept. 27. The emergence patterns for the three sample sources individually and combined are shown in Figures 1 and 2.

Most emergence occurred between March 1 and June 1 (Fig. 3 and 4,). During that period, 1,124 adult shuckworms were collected from all samples (82.2% of the total). The samples from Baldwin, Bullock and Covington Counties produced 467, 440 and 217 adults respectively. Peak emergence occurred during the period April 7 to May 5, when 756 (60% of the total) adults were collected. Of the 244 moths that emerged after June 1, sporadic emergence of individuals occurred until Sept. 27. However, 117 (8.6% of total emergence) were collected during July and 104 (7.6% of the total) in August and September. This is significant in that abscissed fruit are common in July and many feel that the shuckworm, causes its most significant damage to the current year's crop during the months of August and September (Moznette et al., 1931; Payne and Heaton, 1975; McVay an Ellis, 1979; Calcote et al., 1984). Additionally, this study confirmed the reports of Calcote and Hyder (1980) and Calcote (1989) which indicated a bimodal emergence pattern for adults of overwintering larvae. The second activity peak was much lower than that of the initial spring activity but both appeared to occur over similar periods of 6 to 7 weeks duration. Additionally, the second activity

Figure 1. Emergence Patterns of Hickory Shuckworm Adults of the Overwintered Generation.

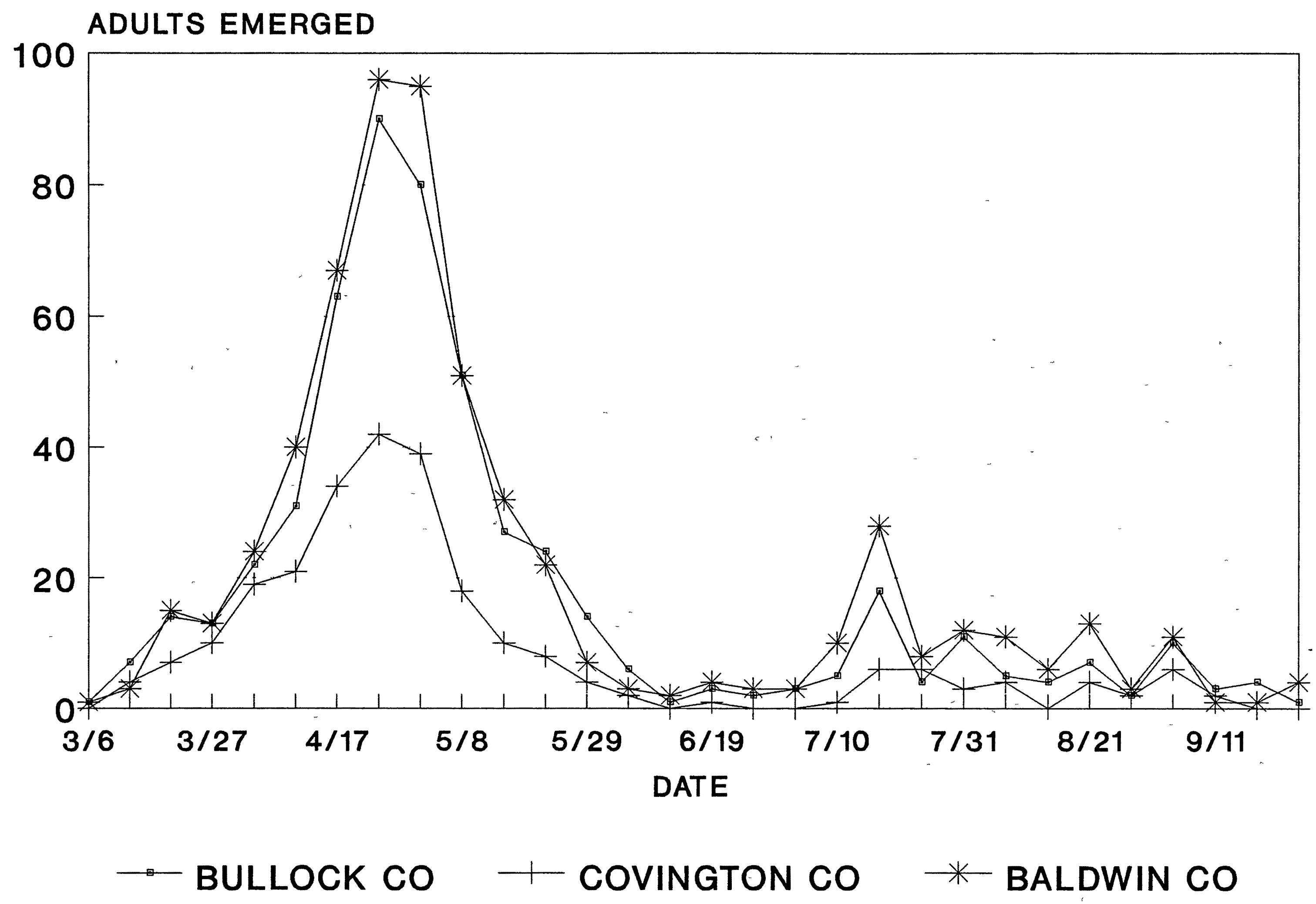

ADULTS EMERGED
100
80
60
40
20
0
3/6
3/27
4/17
5/8
5/29
6/19
7/10
7/31
8/21
9/11
DATE
BULLOCK CO
COVINGTON CO
BALDWIN CO

Figure 2. Combined Emergence Patterns of Hickory Shuckworm Adults of the Overwintered Generation.

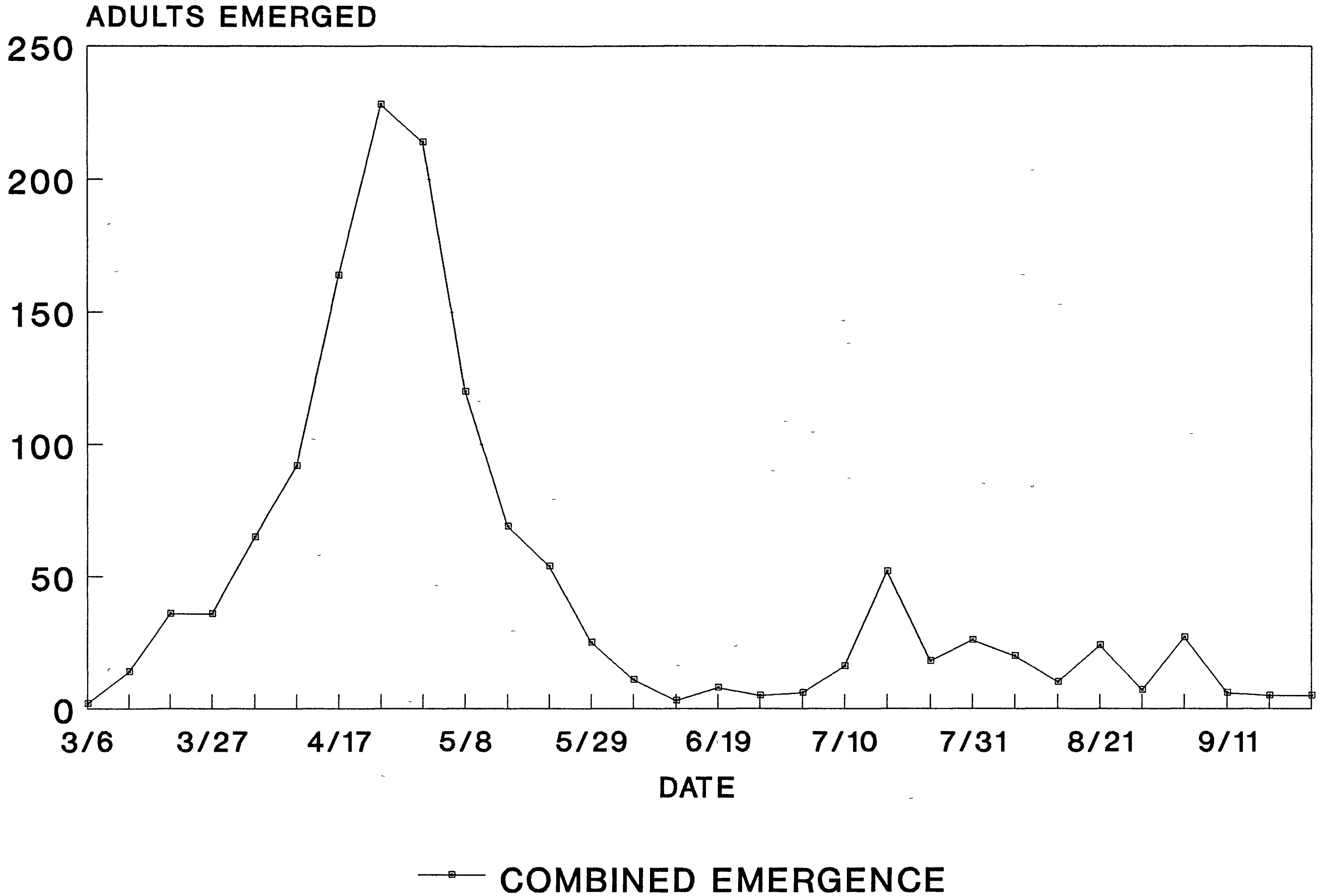

ADULTS EMERGED
250
200
150
100
50
0
3/6
3/27
4/17
5/8
5/29
6/19
7/10
7/31
8/21
9/11
DATE
COMBINED EMERGENCE

Figure 3. Cumulative Emergence of the Overwintered Generation of the Hickory Shuckworm by Sample Source.

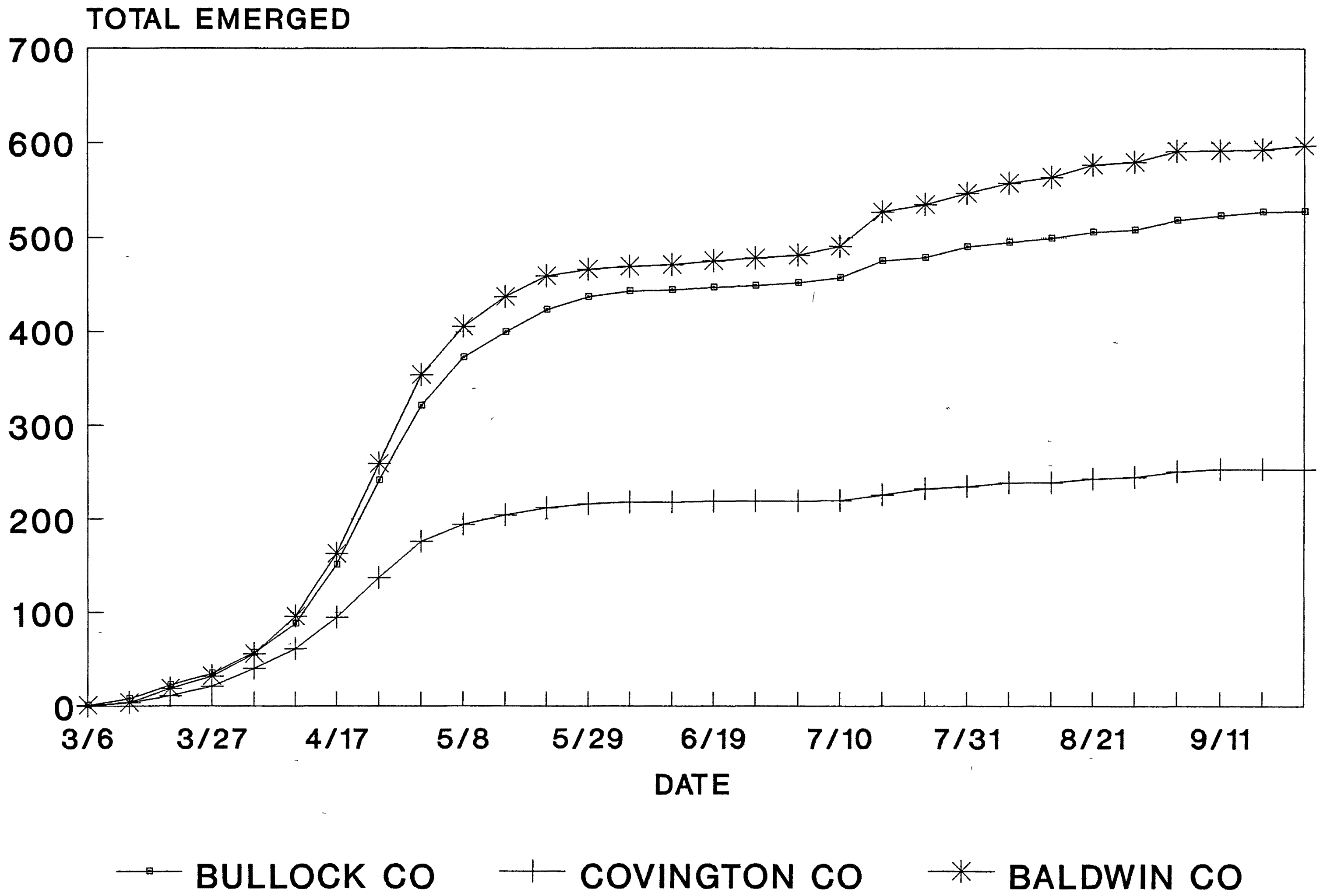
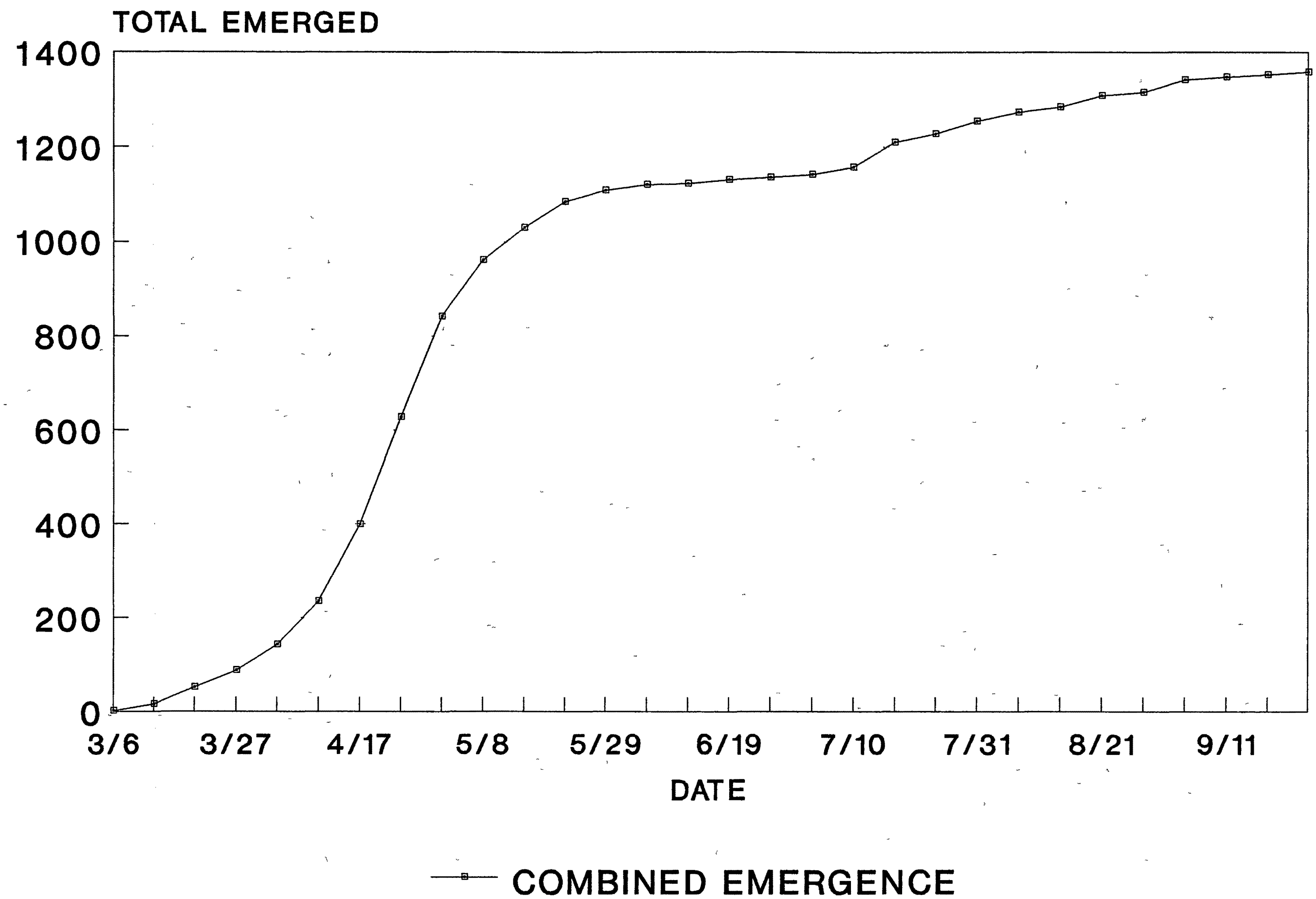

TOTAL EMERGED
700
600
500
400
300
200
100
0
3/6
3/27
4/17
5/8
5/29
6/19
7/10
7/31
8/21
9/11
DATE
BULLOCK CO
COVINGTON CO
BALDWIN CO

Figure 4. Combined Cumulative Emergence of Adults of the Overwintered Generation of the Hickory Shuckworm.


TOTAL EMERGED
1400
1200
1000
800
600
400
200
0
3/6
3/27
4/17
5/8
5/29
6/19
7/10
7/31
8/21
9/11
DATE
COMBINED EMERGENCE

period may be more important from a crop damage standpoint as the majority of adults of the spring emergence go primarily to native hickories (Moznette, 1938; 1941).

Seasonal Population Trends

The seasonal trends of C. caryana in two Alabama pecan orchards are presented in Figures 5 and 6. In both surveyed orchards, the greatest activity occurred during March and April, coinciding with the emergence of the bulk of adults from the overwintering generation. This period of activity ended in mid-May at both locations. Only sporadic activity was evident during the months of June and July and a small surge of activity was detected ca. the first week of August. This was followed by a late activity period which began in early September and peaked in the late September to early October time period. These results agree with reports by Tedders and Osburn (1967), Tedders et al. (1972) and Gentry et al. (1975), all of whom utilized blacklight traps to determine population trends. Interestingly, however, the pheromone traps did not appear to detect the smaller activity peaks during the months of June, July and August to the same degree as the blacklight traps. These activity periods coincided with adult activity of generations 2, 3 and 4 of the shuckworm in the Southeast. All three of these generations are damaging to commercial orchards. Generations 2 (June) and 3 (July) can cause losses due to fruit abscission, and generation 4 (August) contributes

Figure 5. Seasonal Population Trends of the Hickory Shuckworm Determined by Pheromone Traps in Mobile Co., AL.

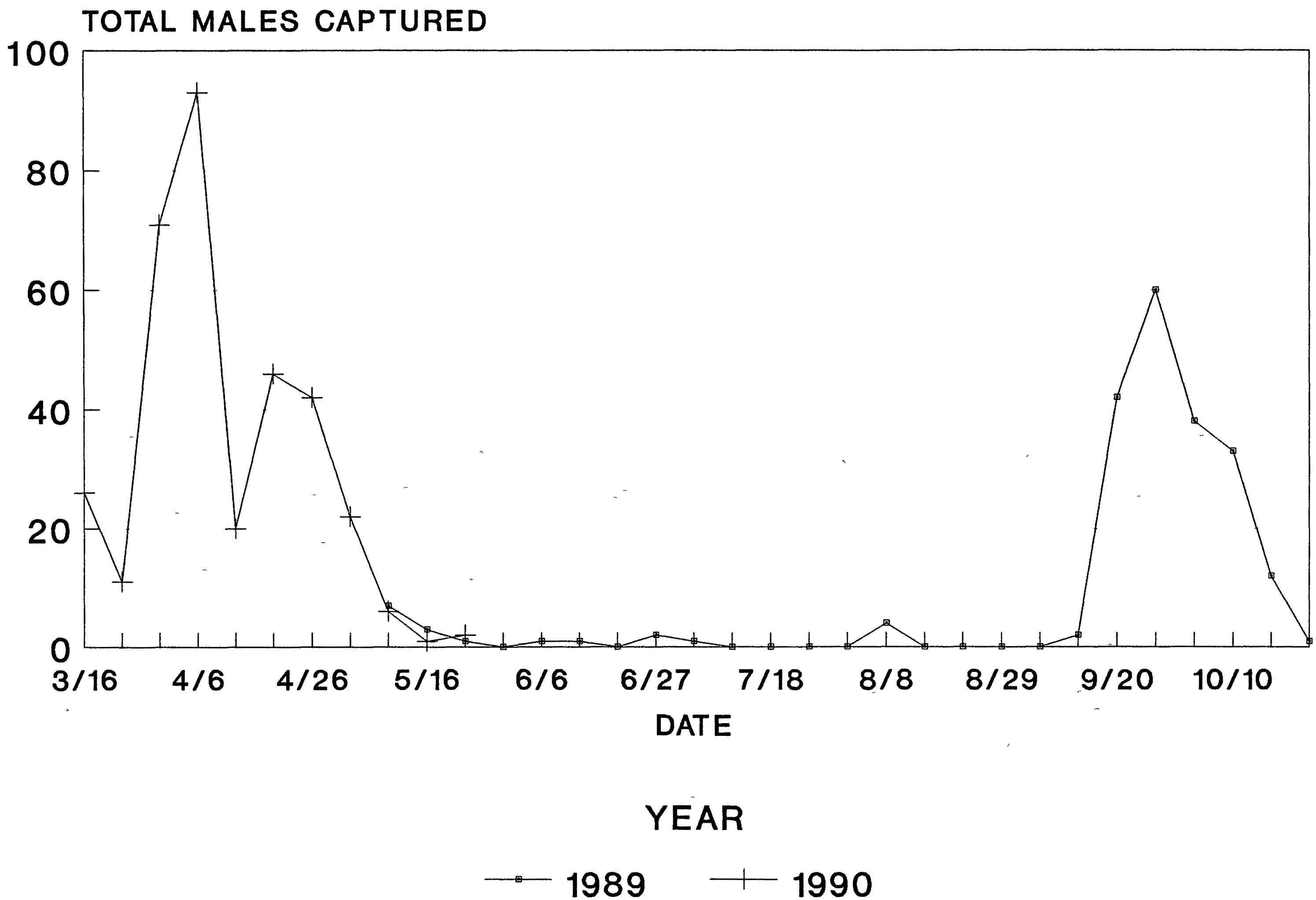
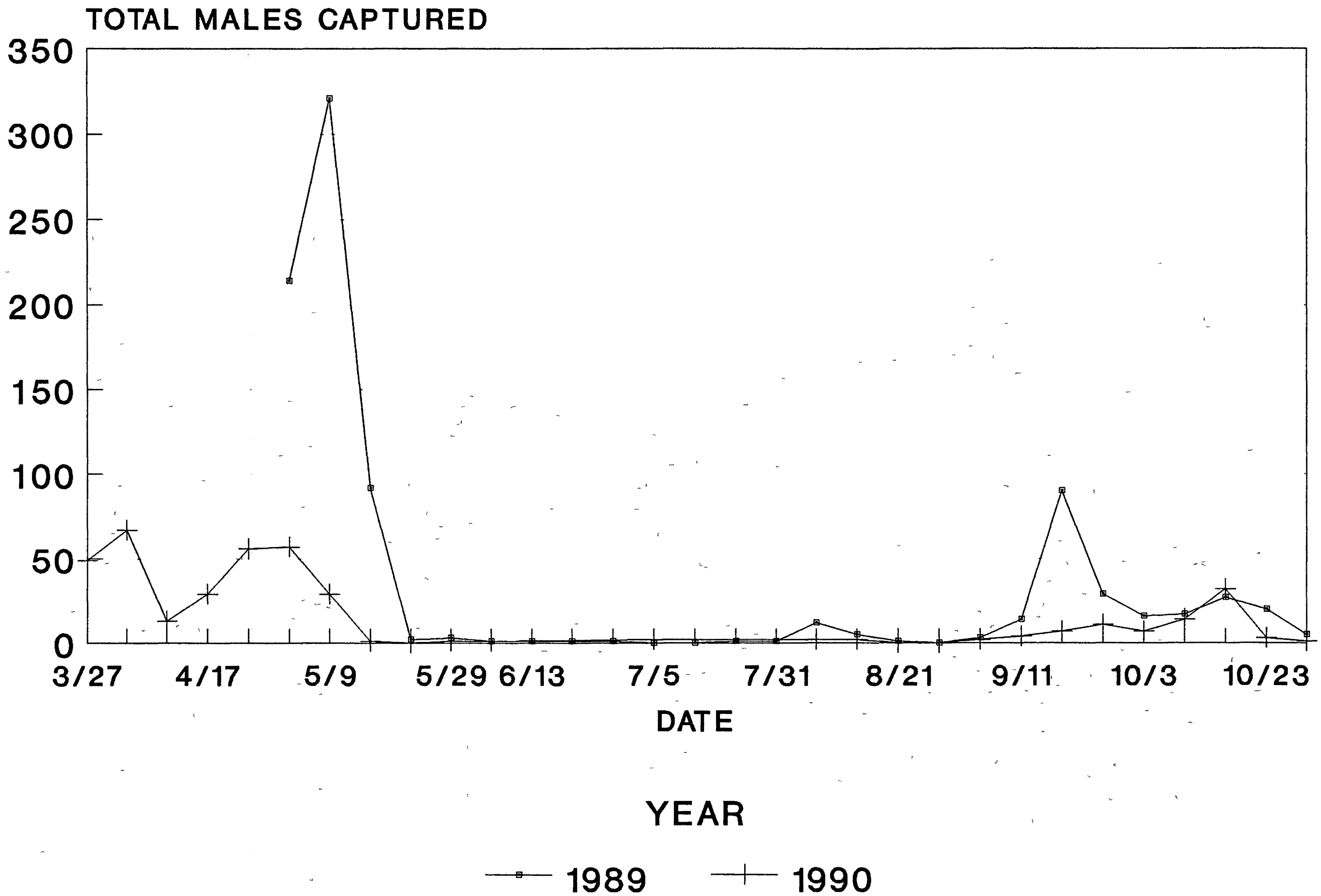

TOTAL MALES CAPTURED
100
80
60
40
20
0
3/16
4/6
4/26
5/16
6/6
6/27
7/18
8/8
8/29
9/20
10/10
DATE
YEAR
1989
1990

Figure 6. Seasonal Population Trends of the Hickory Shuckworm Determined by Pheromone Traps in Baldwin Co., AL.


TOTAL MALES CAPTURED
350
300
250
200
150
100
50
0
3/27
4/17
5/9
5/29
6/13
7/5
7/31
8/21
9/11
10/3
10/23
DATE
YEAR
1989
1990

heavily to the late season damage described in Chapter I. Tedders et al. (1972) reported 88.5% of females captured in blacklight traps had been mated prior to capture. This, considered along with the lack of activity detected by the pheromone traps during these generations suggest that much of the infestation and resulting damage attributable to generations 2-4 may be due to movement into the orchard by mated adults from nearby foci in native hickory trees. This is further supported by the indications of increased activity with succeeding generations throughout the season (generations 2-5). As more progeny are able to complete development in the pecan orchard with each generation, more unmated males are available that may be attracted to the sex pheromone. Future research using the C. caryana sex pheromone should explore this possibility.

Nocturnal Activity Patterns

Of 262 adult male shuckworms captured at hourly intervals following sunset in 1989 and 1990, 180 (68.7%) were taken during the first 4 hours (Table 1, Figure 7). Fifty males were collected during hours 9 to 12 with the peak of activity occurring during hours 9 and 10, the last two prior to sunrise. At hour 12, the sun had been up for ca. 1 hour. The remaining 32 adults (12.2%) were collected during hours 5 to 8. These data agree overall with the report of Tedders and Edwards (1970) which determined activity patterns with blacklight traps placed in a pecan orchard. Data from pheromone traps indicated slightly less activity during hours 5 to 8 than did light trap data. This indicates that C. caryana adult activity may tend to be more crepuscular than truly nocturnal in Southeastern pecan orchards.

Figure 7. Nocturnal Activity Patterns of the Hickory Shuckworm as Determined by Pheromone Trap Captures.

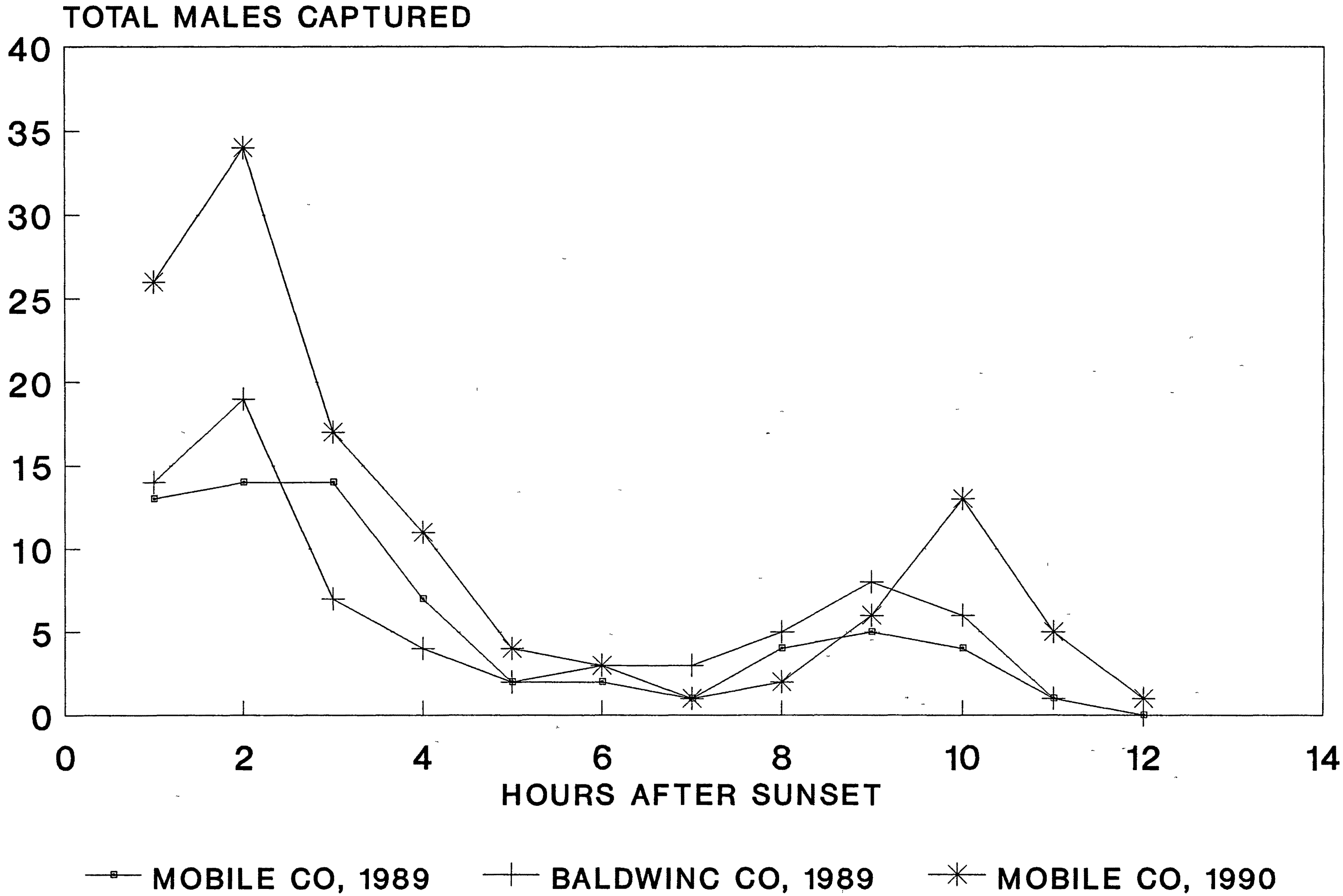

TOTAL MALES CAPTURED
40
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
HOURS AFTER SUNSET
MOBILE CO, 1989
BALDWINC CO, 1989
MOBILE CO, 1990

TABLE 1

NUMBERS OF ADULT MALE HICKORY SHUCKWORM TAKEN AT HOURLY INTERVALS FROM PHEROMONE TRAPS IN ALABAMA PECAN ORCHARDS

		No. Moths Captured Each Hr. After Sunset											
Year	Trap[1]	1	2	3	4	5	6	7	8	9	10	11	12
1989[2]	1B	6	6	3	1	0	1	1	1	2	3	1	0
	2B	5	8	2	2	2	1	1	2	3	2	0	0
	3B	3	5	2	1	0	1	1	2	3	1	0	0
	1M	4	4	5	3	0	0	1	0	0	1	0	0
	2M	2	5	5	2	0	1	0	1	2	1	0	0
	3M	7	5	4	2	2	1	0	3	3	2	1	0
1989 Total	=	27	31	21	11	4	5	4	9	13	10	2	0
1990[3]	1M	5	10	5	2	2	0	0	0	3	4	0	0
	2M	10	10	6	6	2	1	0	1	1	2	1	1
	3M	11	14	6	3	0	2	1	1	2	7	4	0
1990 Total	=	26	34	17	11	4	3	1	2	6	13	5	1
2 Year Total	=	53	67	38	22	8	8	5	11	19	23	7	1
Percent of Total		20	26	15	8	3	3	2	4	7	9	<3	<1

[1]Letters following trap numbers refer to location; B = Baldwin Co., AL; M = Mobile Co., AL.

[2]Values indicate the total number of shuckworm males in each trap over 3 nights of monitoring.

[3]Values indicate the total number of shuckworm males in each trap over 4 nights of monitoring.

Literature Cited

Boethel, D. J., J. T. Criswell, and R. D. Eikenbary. 1974. Incidence of hickory shuckworm in galls of Phylloxera spp. on pecans. J. Econ. Entomol. 67(5): 692-3.

Calcote, V. R. 1989. Seasonal occurrence of the hickory shuckworm in pecan. Proc. S. E. Pecan Growers Assoc. 82: 55-62.

Calcote, V. R., and D. E. Hyder. 1980. Late season emergence of shuckworm from overwintering shucks. Proc. S. E. Pecan Growers Assoc. 73: 75-7.

Calcote, V. R., R. E. Hunter, and T. E. Thompson. 1984. Nutrient flow through the pecan shuck into the nut and disruption of this flow by hickory shuckworm larvae. Proc. S. E. Pecan Growers Assoc. 77: 61-9.

Ellis, H. C., P. Bertrand, M. French, and C. Bruce. 1983. Pecan pest management in Georgia, pp. 89-100. In J. A. Payne [ed.], Pecan Pest Management - Are We There? Misc. Pub. Entomol. Soc. of Am. 13(2).

Gentry, C. R., J. S. Smith, Jr., J. L. Blythe, and G. W. Edwards. 1975. Blacklight lamp provides alternatives to insecticides. Pecan Quarterly. 9(3): 10-12.

Harris, E. D., Jr., N. E. McGlohon, and H. C. Ellis. 1975. Pecan insects and diseases and their control. Ga. Ext. Bull. 644, Univ. of Ga., Athens. 20 pp.

McVay, J. R., G. R. Strother, W. S. Gazaway, R. H. Walker, and J. Boutwell. 1978. The Alabama pecan pest management program. Pecan South 5(3): 104-9, 135-9.

McVay, J. R., and H. C. Ellis. 1979. Extension approaches to pecan pest management in Alabama and Georgia, pp. 121-49. In D. J. Boethel and R. D. Eikenbary [eds.], Pest Management Programs for Deciduous Tree Fruits and Nuts. Plenum Press, New York.

McVay, J. R., and P. M. Estes. 1989. Insect and mite pests, pp. 105-25. In W. D. Goff, J. R. McVay and W. S. Gazaway [eds.], Pecan Production in the Southeast: a guide for growers. Ala. Coop. Ext. Ser. Pub. ANR-459, Auburn Univ.

Moznette, G. F. 1938. Some important biological factors in the control of hickory shuckworm on pecan. Proc. S. E. Pecan Growers Assoc. 32: 11-4.

Moznette, G. F. 1941. Progress in the control of the hickory shuckworm of pecan. Proc. S. E. Pecan Growers Assoc. 34:42-8.

Moznette, G. F., T. L. Bissel, and H. A. Adair. 1931. Insects of the pecan and how to combat them. USDA Farmers Bull. 1954. 59 pp.

Osburn, M. R., W. C. Pierce , A. M. Phillips, J. R. Cole, and G. E. KenKnight. 1966. Controlling insects and diseases of the pecan. USDA Agric. Handb. No. 240, 55 pp.

Payne, J. A., and E. K. Heaton. 1975. The hickory shuckworm: its biology, effect upon nut quality, and control. Annu. Rep. Northern Nut Growers Assoc. 66: 19-25.

Phillips, A. M., J. R. Large, and J. R. Cole. 1960. Insects and diseases of the pecan in Florida. Fla. Ag. Expt. Sta. Bull. 619, Univ. of Fla., Gainesville. 84 pp.

Smith, J. S., Jr., and W. L. Tedders. 1978. S-2 blacklight traps for capturing certain pecan insects. Pecan South 5(4): 172-4.

Smith, J. S., Jr., W. L. Tedders and C. R. Gentry. 1973. Blacklight trapping of the hickory shuckworm moth in Georgia pecan orchards. Trans. Am. Soc. Agric. Eng. 16(1): 127-8.

Tedders, W. L., and M. Osburn. 1966. Blacklight traps for timing insecticide control of pecan insects. Proc. S. E. Pecan Growers Assoc. 59: 280-2.

Tedders, W. L., and M. Osburn. 1967. Examining blacklight trap collections for small pecan insects. J. Ga. Entomol. Soc. 2: 87-9.

Tedders, W. L., Jr., and G. Edwards. 1970. Activity of hickory shuckworm from collections in traps. J. Econ. Entomol. 63(5): 1610-11.

Tedders, W. L., and G. Edwards. 1972. Effects of blacklight design and placement on catch of adult hickory shuckworms. J. Econ. Entomol. 65(6): 1624-7.

Tedders, W. L., and C. R. Gentry. 1970. Know these pecan enemies -- hickory shuckworm and pecan weevil. Progressive Farmer, Aug., 1970, p. 26.

Tedders, W. L., Jr., J. G. Hartsock, and M. Osburn. 1972. Suppression of hickory shuckworm in a pecan orchard with blacklight traps. J. Econ. Entomol. 65(1): 148-55.

Todd, L. 1967. A spring emergence study of the hickory shuckworm, _Laspyresia caryana_. Tex. Pecan Growers Assoc. Proc. 46: 80-5.

Van Duyn, J. W. 1967. Emergence of overwintering shuckworm in north Florida. Proc. S. E. Pecan Growers Assoc. 211: 26-31.

CHAPTER III

EFFECTS OF TRAP DESIGN AND PLACEMENT ON CAPTURE OF HICKORY SHUCKWORM MALES WITH SEX PHEROMONE

Introduction

The use of pheromone technology in IPM systems which relate to orchard crops has been investigated widely. In such efforts, several basic parameters are commonly delineated to the greatest degree possible prior to the incorporation of this technology into an actual system. Key among these are trap design and placement in relation to captures of the insect species monitored (Wall, 1989). Systems involving tree crops, especially apples, have been investigated by many researchers. Efforts involving trap design have been made in apples for the codling moth, Cydia pomonella (L.) (Howell, 1972; McNally and Barnes, 1980; Riedl, 1980; Westigard and Graves, 1976) which is closely related to the hickory shuckworm. Similar investigations have been conducted in apple orchards for monitoring and control programs using pheromones of various lepidopterous species as well as other insect pests (Bode et al., 1973;

Hoyt et al., 1983; David and Horsburgh, 1989). Trap design has also been shown to be important in the use of pheromones for monitoring pests in other tree cropping systems and vineyard situations (Taschenberg et al., 1974; Younce et al., 1976; Sanders, 1978; Steck and Bailey, 1978; Younce et al., 1979; AliNiazee, 1983; Danko and Jubb, 1983; Sanders, 1986).

The placement of pheromone traps in these situations has also been demonstrated to have great effect on the ability of traps to attract and capture target species. Trap height, directional orientation and other locational parameters within the tree canopy or monitored area have all proven important (Younce et al., 1976; Riedl et al., 1979; Younce et al., 1979; McNally and Barnes, 1981; AliNiazee, 1983; Danko and Jubb, 1983; Hoyt et al., 1983; David and Horsburgh, 1989). These efforts indicate that the factors affecting trap efficiency are complex and as many aspects of design and placement as possible need to be investigated prior to reliance on pheromone traps as definitive indicators of insect populations (Elkington and Carde, 1981).

In the pecan orchard agro-ecosystem there have been no reports published concerning the physical use parameters for pheromones. Tedders and Edwards (1972) reported on blacklight trap design and placement as they affected the capture of adult C. caryana. Because of differences in use of blacklight and pheromone traps, this work provides little information applicable to pheromone technology. The data did indicate that there were capture differences due to height of the trap in the tree canopy. This chapter deals with a series of studies designed to identify some of the parameters for using pheromone traps to monitor the hickory shuckworm in an IPM program.

Materials and Methods

General

All studies described in this chapter have certain characteristics in common. All were conducted in commercial pecan orchards in Alabama and orchards and individual trees chosen for each study had to meet standard criteria. Orchard selection criteria were: [1] well maintained orchard with a good record of production, [2] a confirmed recent history of hickory shuckworm infestation, [3] at least 8.1 ha (20 acres) in size and consisting primarily of trees of the Stuart variety, [4] a minimum of 30 trees per hectare (12 per acre; maximum spacing of 18.3 m (60 ft) both in row and between rows), and [5] trees of uniform size, 18 to 26 m in height (60 to 85 ft), and age (mature trees 50 yr old or older).

Within each orchard, individual trees were chosen for study purposes by the following criteria: [1] Stuart variety, [2] healthy tree with no visible mechanical or other damage, [3] additional trees of the same variety located on each directional facing from the data tree (e.g. the data tree was not adjacent to a blank spot or "skip" in the orchard), [4] no data tree was to be located on the orchard perimeter, and [5] data trees were separated by at least two non-data trees (54.6 m). Once all candidate trees meeting these criteria were identified, those to be included in each study were chosen in a completely random manner.

Unless otherwise indicated, all traps were suspended at the desired height in each data tree with rope and pulley arrangements. Pulleys were affixed to limbs with coated wire to prevent limb damage. Traps were raised and lowered to the height of the pulley with 3.18 mm (1/8 inch) nylon cord. Attached to trap bottoms were lengths of nylon twine to facilitate lowering of the traps as they were not heavy enough to drop from their own weight. When traps were in position, both the cord and twine were tied off to zinc-coated nails driven into the tree trunk.

All studies were conducted with the commercial hickory shuckworm sex pheromone lure manufactured by Scentry, Inc. of Buckeye, AZ. Each lure consisted of a grey rubber septum charged with 50 micrograms of the field blend discussed earlier.

Trap Design

Three commercially available pheromone trap designs were tested for effectivness in monitoring *C. caryana*. Designs chosen were: [1] Pherocon Ic traps with spacers,

[2] Pherocon Icp traps with notched bottoms and spacers, and [3] Pherocon II traps. The three designs were chosen because they were readily available commercially, easy to assemble and use, and have been recommended for monitoring of other Tortricid moths (Bode et al., 1973; Sanders, 1978; Riedl, 1980; AliNiazee, 1983; Danko and Jubb, 1983; David and Horsburgh, 1989).

The Pherocon Ic trap is widely used for monitoring programs involving pheromones of lepidopterous insects and is the trap marketed commercially with the _C. caryana_ lure. The trap is commonly called a "wing" trap. Insects attracted to the trap are captured in a film of sticky material coating the inner side of the trap bottom or liner. The top, identical in size and shape, protects the retentive surface and captured insects from the elements. The bottom liner is constructed of coated cardboard and is replaceable while the top is plastic. White was the color chosen for both sections for this study. Top and bottom are assembled together by means of a wire hanger and plastic spacers separate the two portions, allowing easy access for the insects. The rubber septum charged with sex pheromone was placed in the center of the retentive surface. The Pherocon Icp trap design is identical to that of the Ic except that a notched area 6 cm wide and 3.5 cm deep is incorporated into each end of the trap bottom. Ostensibly, this is to allow the pheromone plume to be more readily released. The Pherocon II is a 1-piece trap that requires no assembly and is more easily placed in a monitoring system. When opened, the coated cardboard trap is diamond shaped with the entire inner surface coated with a sticky substrate as the retentive surface. Septa were placed in types Icp and II in the same manner as in the Ic trap.

The study was conducted in a 16.2 ha pecan orchard in Mobile Co., AL in 1989 and the spring of 1990. Fifteen trees were chosen and randomly assigned a treatment (trap type). Five of each trap type were installed 9.14 m (30 ft) above the orchard floor on the west side of the tree but near the vertical centerline of the canopy. Traps and lures were installed on May 2, 1989 and monitored at 7-day intervals until Oct. 25. In 1990, installation was on Mar. 6 and monitoring continued until May 29. The number of *C. caryana* males captured in each trap was determined on each monitoring date. In both years, lures and trap bottoms (liners) were replaced every 28 days to insure optimum performance of both. The old lures and liners were disposed of away from the study site. Data were analyzed by Analysis of Variance and tested for Least Significant Differences (Cochran and Cox, 1957; Steel and Torrie, 1980; SAS Institute, 1988; SAS Institute, 1988b).

Cardinal Direction

The effect of pheromone trap placement by compass direction was evaluated in Covington Co., AL. In 1989, the study was conducted in a 12.15 ha block of mature Stuart trees located within a 40.5 ha orchard. The canopy of each of five trees was visually divided into directional quadrants and one Pherocon Ic trap placed in the center of each. Thus, 4 traps were placed in each tree, corresponding to each of the cardinal directions on line with the tree trunk. All traps were suspended 9.14 m above the orchard floor and were located at the midpoint between the tree center and the canopy dripline (ca. 4.57 m from the tree center). The traps were installed and baited with the Scentry lure on May 17 and monitored at 7-day intervals until Oct. 7. Lures and trap liners were replaced every 28 days. The number of males captured in each trap on each monitoring date were determined.

Due to an extremely light infestation in the orchard in 1989, the study was relocated in the spring of 1990. The new study orchard was located 32 km to the southeast in the same county, was predominately Stuart in composition, and 20.25 ha in size. The study was identical to that conducted in 1989 except for the duration of monitoring. Traps were placed and baited on March 7 and monitored until June 30. Lures and liners were replaced every 28 days and data were recorded as in 1989. Results were subjected to Analysis of Variance and tested for Least Significant Differences (P=0.05).

Trap Height

The study on effects of trap height within the tree canopy, was intiiated in 1989 in a 32.2 ha orchard in Baldwin Co., AL. Two Pherocon Ic traps were suspended in each of seven data trees (replications), in the west face of the canopy near the vertical center of the tree. One trap was located 9.14 m (30 ft) above the orchard floor the other at 4.57 m (15 ft) above that surface. The 9.14 m height was considerred the maximum height that an average producer could establish a trap monitoring system. Trees in the orchard were ca. 21.3 to 27.4 m tall (70 to 90 ft).

Baited traps were installed on Apr. 25, 1989 and monitored at 7-day intervals until Oct. 30. Lures and liners were replaced at 28-day intervals. The number of adult male shuckworm moths captured in each trap during each 7-day period were determined.

In 1990, an additional 14 trees were included in the trial. Seven trees were equipped with a single Pherocon Ic trap located 9.14 m above the orchard floor. A single trap was suspended 4.57 m above the soil surface in the other seven. The original seven trees were re-equipped in the same manner as in 1989. This was done in an attempt to remove trap competition effects from the analysis.

Baited traps were placed in the orchard on Mar. 20, 1990 and again monitored at 7-day intervals until Oct. 30. Lures and liners were replaced as previously described. Data were recorded as in 1989, and data were subjected to

Analysis of Variance.

Within-Canopy Horizonal Placement

A 16.2 ha orchard in Bullock Co., AL was selected for a study to determine the effects of horizontal trap location within the pecan canopy. In 1989, Pherocon Ic traps were suspended in three locations in each canopy of 9 trees (replications). In order to insure that all traps were at the same height (9.14 m), a 3.18 mm diameter rope was stretched from a major limb or the primary trunk of each data tree to the neighboring tree to the west at that height. The attachment point in the data tree was slightly east of the vertical center of the canopy. Pulleys were affixed to the rope at each of three locations and secured to negate any movement out of position. Locations were: [1] the exact center of the tree, [2] the midpoint between the center and the dripline of the canopy, and [3] at the canopy dripline (ca. 9.14 m from the tree center). Therefore, the trap locations were fixed at the canopy center, at a point 4.57 m to the west (midway point), and at the dripline.

Traps baited with the Scentry lure were installed on Apr. 26, 1989, and monitored weekly until Oct. 27. The study was repeated in the same location and trees during the spring of 1990, except that installation was on Apr. 23 and the test was terminated on June 12. Traps were monitored on a 7-day schedule with lures and liners replaced at 28-day intervals. The number of males captured on each monitoring date for each trap were determined.

In 1990, the study was redesigned to monitor shuckworm activity in the late summer and fall. Seven trap arrangement schemes were installed with four replications of each. Trap arrangements were: [1] three traps per tree, one at each of the three locations, [2] two traps, one each at the tree center and the canopy midpoint location, [3] two traps, one each at the tree center and dripline locations, [4] two traps, one each at the canopy midpoint and dripline locations, [5] one trap at the tree center location, [6] one trap at the canopy midpoint location and [7] one trap at the dripline location. This arrangement was utilized to minimize confounding effects of trap competition on trap location effects. Traps were baited and installed on Aug. 7, 1990, and monitored at 7-day intervals until Oct. 30. Lure and liner replacement and data collection were as previously described. Data for both years were subjected to Analysis of Variance and tested for Least Significant Differences (P=0.05).

Results and Discussion

Trap Design

The Pheocon Ic trap captured significantly more *C. caryana* males during both years than did the Pherocon II trap and numerically more than the Pherocon Icp (Table 2).

Pherocon Icp traps captured more than did the Pherocon II but the differences were not significant (ANOVA, LSD: P=0.05) (Tables 2 and 3).

The numbers of hickory shuckworm males captured in 1990 were larger (P=0.01) than in 1989. However, there was no evidence of an interaction of trap type by year and the response pattern of capture to trap type was the same for both years. Due to the season long nature of the study, which encompassed several generations of the shuckworm, significant differences due to monitoring date also were evident. This was an expected result when succeeding generations of a multivoltine species were plotted through time, and appeared to have no bearing on trap type effects.

These results agree with those found with several other Tortricid moth species (Bode et al., 1973; Danko and Jubb, 1983; AliZiazee, 1983; David and Horsburgh, 1989). The Pherocon Ic trap type has a greater retentive surface than the other trap types but its greater efficiency in capturing C. caryana males could not be attributed to that alone. AliNiazee (1983) found no significant relationship between total capture and retentive surface when comparing several traps, including the three tested here. He suggested that trap design efficiency was related to plume characteristics of the attractant, male response behavior, entrance and landing convenience of the trap and the efficiency of the retentive surface. Others have referred to a loss of efficiency due to repeated captures on the retentive surface

TABLE 2

TOTAL NUMBERS OF HICKORY SHUCKWORM MALES CAPTURED DURING 1989 AND 1990 BY TRAP TYPE

	Total Captured[1]		
Trap Type	1989	1990	Total
Pherocon Ic	208	340	548
Pherocon Icp	136	290	426
Pherocon II	78	183	261

[1]Combined totals for five replications of each trap type.

TABLE 3

EFFECT OF TRAP DESIGN ON CAPTURES
OF HICKORY SHUCKWORM MALES

	Mean[1] No. of Males / Trap / 7-day Period		
Trap Design	1989	1990	Average
Pherocon Ic	1.67a	6.18a	3.04a
Pherocon Icp	1.09ab	5.29ab	2.37ab
Pherocon II	0.62 b	3.45 b	1.49 b

[1]Means not followed by the same letter in the same column are significantly different (LSD: P=0.05), (for 1989, no. of observations = 55, EMS = 13.59, SEM = 0.50; for 1990, no. of observations = 125, EMS = 13.59, SEM = 0.33; and for the two year average, no. of observations = 180, EMS = 15.36, SEM = 0.29) (LSD value = 0.9).

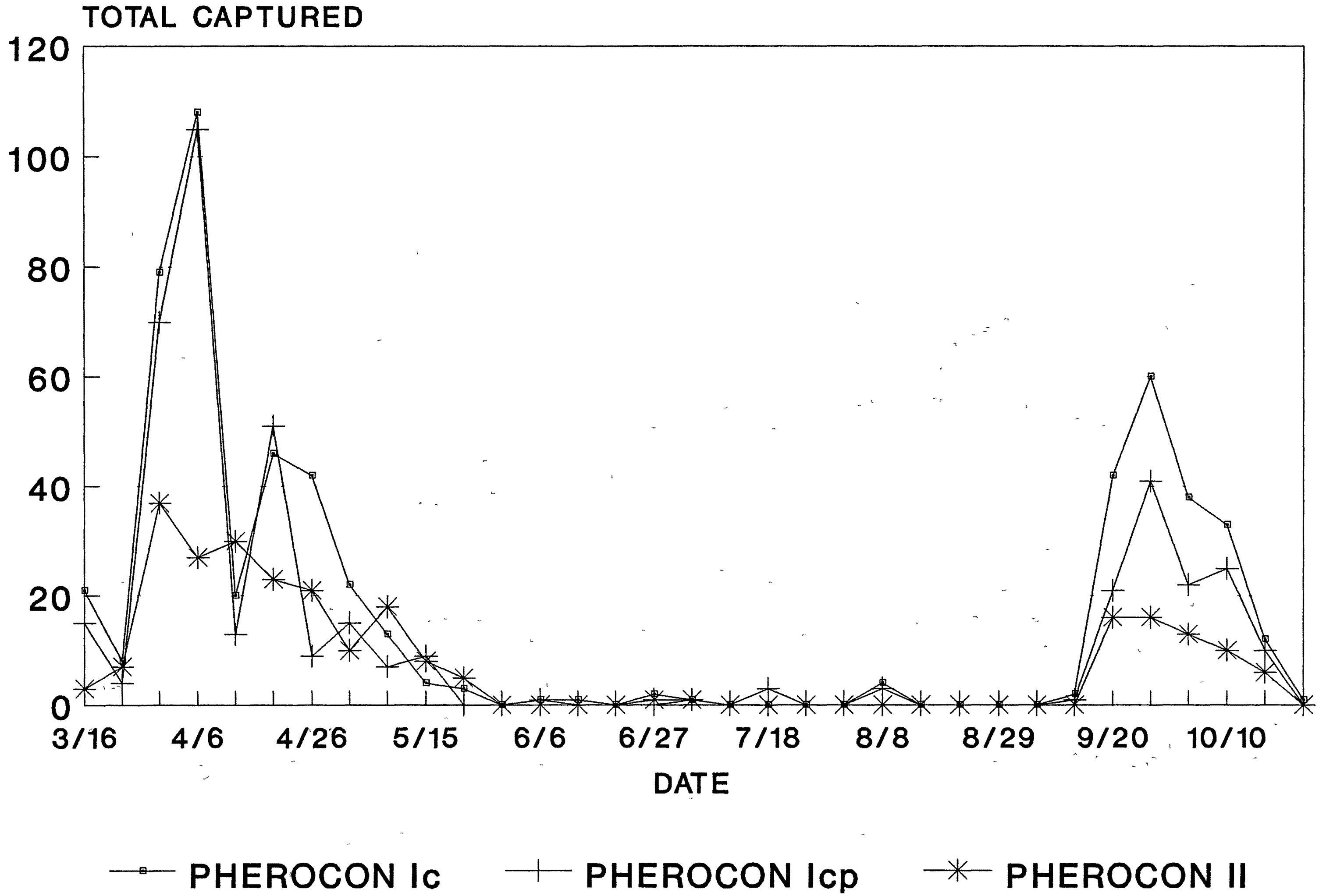
(Brown, 1984; McNalley and Barnes, 1984). This should not have been a factor in the present study because the entire Pherocon II trap and the retentive surface liners of types Ic and Icp were replaced at 28-day intervals as suggested by Riedl (1980).

Although the Pherocon Ic trap captured the greatest number of moths, all appear to monitor general population trends equally well (Fig. 8). The ultimate choice of trap type should depend on the intent of the monitoring system (David and Horsburgh, 1989). If pheromone trap captures are to be used as biofix points (Riedl et al., 1976) then the Pherocon II might be most suitable due to convenience and ease of use and maintenance (Jubb and Danko, 1982). This, of course, assumes equal efficiency in first moth capture among designs. If, however, moth numbers are important for triggering control measures or precisely defined peaks are desired (Bode et al., 1973), the Pherocon Ic trap would be preferable.

Cardinal Direction

Pherocon Ic traps placed to correspond with the four cardinal directions captured a total of 41 male shuckworm moths in 1989. During 1990, the study was relocated as previously described and traps captured 304 adult males. Total captures by direction are indicated in Table 4 as well as the 2-year totals.

Figure 8. Captures of Adult Male Hickory Shuckworms by Trap Type.


TOTAL CAPTURED
120
100
80
60
40
20
0
3/16
4/6
4/26
5/15
6/6
6/27
7/18
8/8
8/29
9/20
10/10
DATE
PHEROCON Ic
PHEROCON Icp
PHEROCON II

Analysis of Variance indicated significant differences in numbers of adult moths captured due to direction in both 1989 (P=0.05) and 1990 (P=0.01); pooled analysis indicated differences were significant at the P=0.01 level for the two years combined. Traps on the East and North sides of the trees captured significantly more adult males than those on the West and South (Table 5).

Analysis of Variance also indicated a significant difference between the average number of males captured in the two years of the study. This was probably due to location as the study was relocated in 1990. It was concluded that this difference was due to population size as there was no year (location) by direction interaction indicated. In fact the directional results were the same for both years (locations) with the numbers for any direction in 1990 being greater than those in 1989. These analyses indicate that the averaged over years for directional placement were interpetable. Differences due to monitoring dates throughout the study period were also indicated but were expected, as previously explained, and appeared to have little or no bearing on the main effects. The relative proportion of trap captures by direction are shown in Fig. 9 and the pattern of capture by year and direction are shown in Fig. 10. Figure 11 demonstrates that the pattern of total captures by direction was essentially the same for both years.

TABLE 4

TOTAL NUMBERS OF HICKORY SHUCKWORM
MALES CAPTURED IN 1989 AND 1990
BY CARDINAL DIRECTION

		Cardinal Direction			
Year		East	North	South	West
1989		20	14	5	2
	Percent of Total =	48.8	34.2	12.2	4.8
1990		110	94	48	52
	Percent of Total =	36.2	30.9	15.8	17.1

Values are the combined totals for five replications (traps) for each cardinal direction.

TABLE 5

EFFECT OF CARDINAL DIRECTION
ON CAPTURES OF MALE
HICKORY SHUCKWORM

Cardinal Direction	Mean[1] No. of Males / Trap / 7-day Period		
	1989	1990	Average
East	0.40a	1.83a	1.18a
North	0.28a	1.53a	0.96a
South	0.10 b	0.80 b	0.48 b
West	0.04 b	0.87 b	0.49 b

[1]Means not followed by the same letter in the same column are significantly different (LSD: P=0.05), (for 1989, observations = 50, EMS = 0.385, SEM = 0.088, LSD value = 0.27; for 1990, observations = 60, EMS = 2.457, SEM = 0.202, LSD value = 0.62; for the two year average, observations = 110, EMS = 1.421, SEM = 0.114, LSD value = 0.4).

Presumably, differences in trap captures by direction are due to the influence of air currents on the pheromone plume (Hoyt et al., 1983; David and Horsburgh, 1989). In the study area, the prevailing winds were from the southwest throughout the period sampled. However, other factors such as temperature, light intensity, and male flight behavior may play an important role (AliNiazee, 1983). A possibility as yet unexplored in the pecan agro-ecosystem is that of a tree- or fruit-emitted karimone which is initially attractive to the insect and serves to place the individual in the proximity of pheromone traps or other monitors. In this study, traps at different directional placements were possibly in direct competition with each other and cannot be considered as independent treatments. results may have been different if individual traps were hung in separate trees.

<u>Trap Height</u>

As reported in Chapter II, pheromone traps baited with the sex lure of <u>C. caryana</u> did not appear to be greatly effective for monitoring generations 2, 3 and 4 of the species in pecan orchards. This trend was true for this study as well. Only trap counts of adults of the over-wintering generation (gen. 1) and those of generation 5 were sampled adequately, although traps were monitored throughout the season. Therefore, data for both 1989 and 1990 were subjected to Analysis of Variance by individual generation

Figure 9. Proportion of Hickory Shuckworm Males Captured by Direction.

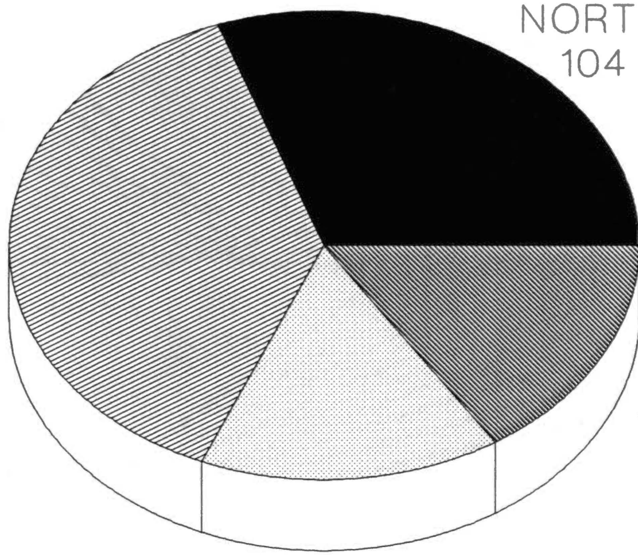

NORTH
104
EAST
130
WEST
54
SOUTH
53

Figure 10. Pattern of Capture of Male Hickory Shuckworm by Direction and Year.

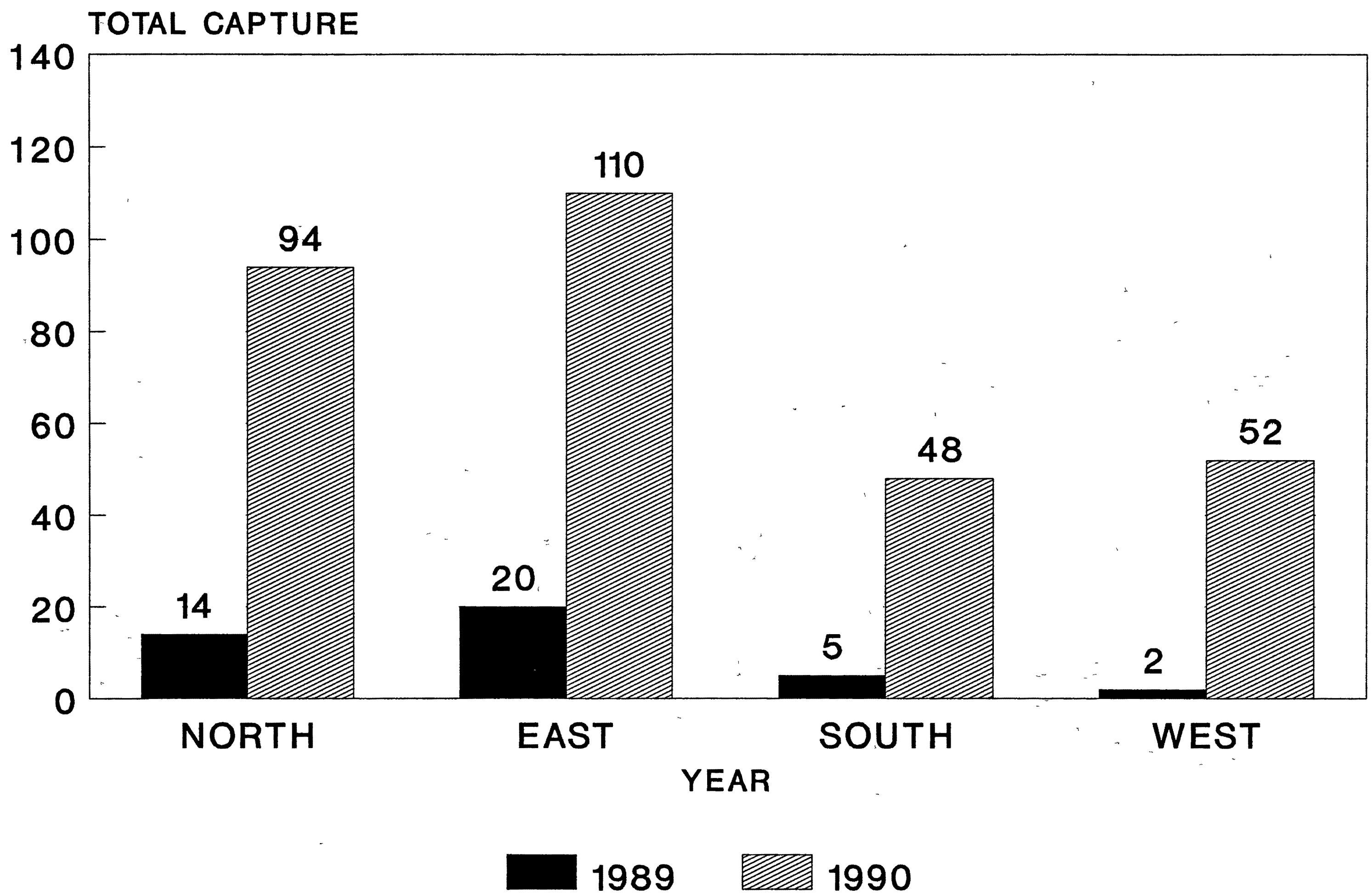
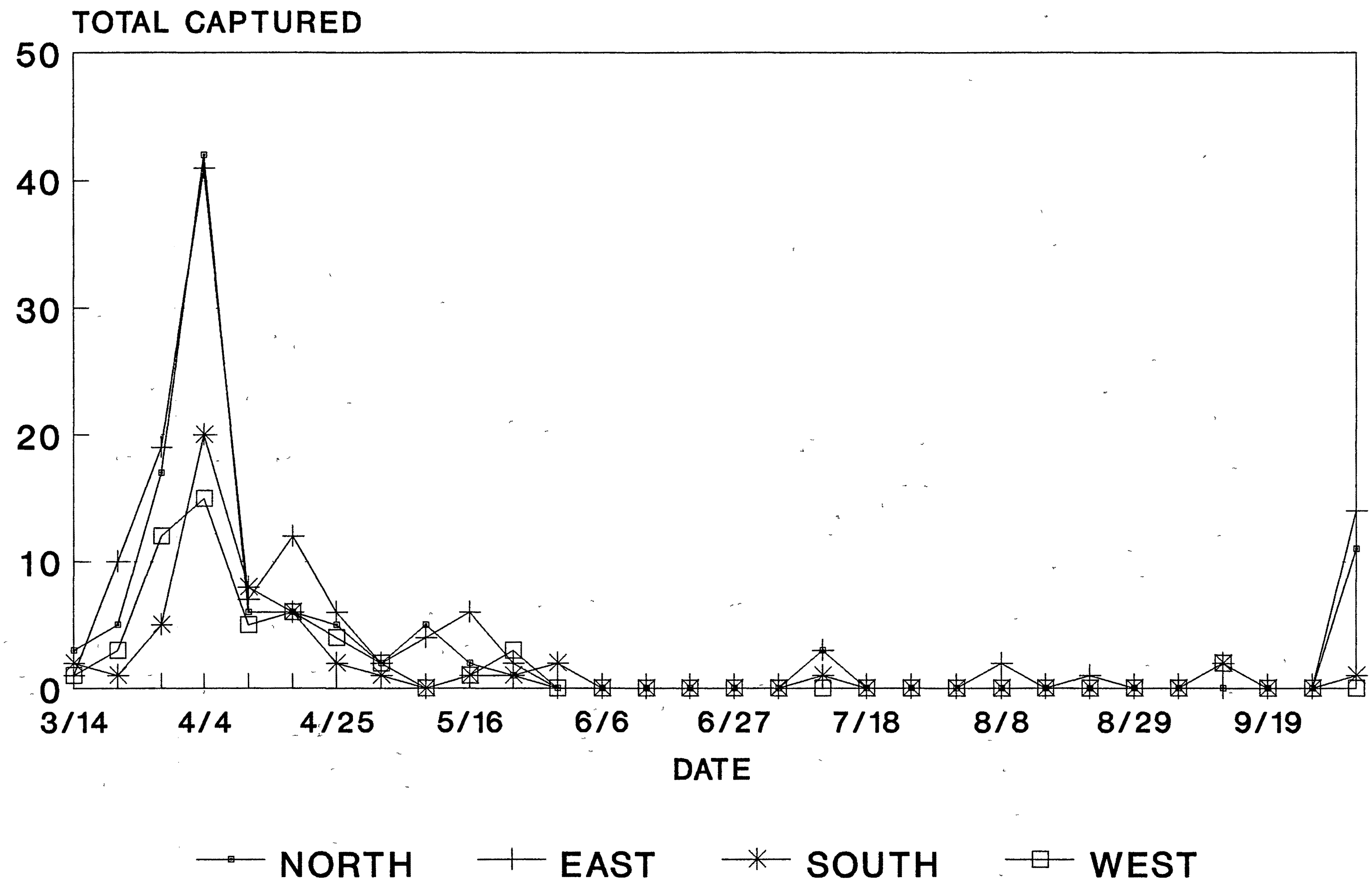

TOTAL CAPTURE
140
120
100
80
60
40
20
0
94
110
14
20
5
48
2
52
NORTH
EAST
SOUTH
WEST
YEAR
1989
1990

Figure 11. Pattern of Captures of Male Adult Hickory Shuckworm by Directional Facing of Trap.


TOTAL CAPTURED
50
40
30
20
10
0
3/14
4/4
4/25
5/16
6/6
6/27
7/18
8/8
8/29
9/19
DATE
NORTH
EAST
SOUTH
WEST

as indicated by the capture of adult males. Additionally, all data for each year were analyzed as a single entity and finally, data from both years were pooled and subjected to Analysis of Variance. Total captures of male C. caryana and the mean numbers captured per trap are presented in Table 6 by year, generation, trap height and experimental method (one or two traps per tree).

Analysis of Variance for 1989 data, collected from trees containing traps at both heights, indicated no differences in number of males captured due to trap height during generation 1. The only significant differences indicated were due to date, which was to be expected. This was also true for all other year and generational data analyzed. Analysis of data for generation 5 indicated highly significant differences (P=0.01) in captures due to height. When all data for 1989 were pooled and subjected to analysis, there were significant differences for capture by trap height (P=0.01), generation (P=0.08), dates in generation (P=0.001), and height by dates in generation (P=0.05).

Data for 1990 were analyzed in the same manner with the addition of method (one trap or two traps per tree) as a variable. There were no significant differences in number of captures during the first generation except for date. The same was true for data from generation 5. A pooled analyis of 1990 data indicated significant differences only between generations (P=0.01) and dates in generations (P=0.001).

TABLE 6

CAPTURE OF HICKORY SHUCKWORM
MALES BY TRAP HEIGHT

			Total[1] by Trap Height		Mean[2] Males/ Trap/7-day Per.	
Year	Gen.[3]	Method[4]	9.14m	4.75m	9.14m	4.75m
1989	1	2 Trap	443	186	15.82a	6.64a
	5	2 Trap	141	22	2.52a	0.39b
	Gen. Combined		584	208	6.95a	2.48b
1990	1	2 Trap	187	111	2.97a	1.76a
	5	2 Trap	58	23	0.83a	0.33a
	Gen. Combined		245	134	1.84a	1.03a
	1	1 Trap	230	224	3.65a	3.56a
	5	1 Trap	73	54	1.04a	0.77a
	Gen. Combined		303	278	2.28a	2.09a
Pooled			1132	620	2.79a	1.06b

[1]Combined totals for 7 traps (replications) in each method at each height.

[2]Paired means not followed by the same letter are significantly different (ANOVA: P=0.05), (for 1989; Gen. 1 values were, EMS = 367.99, obs. = 28; Gen. 5 values were, EMS = 20.81, obs. = 56; Combined Gen. values were, EMS = 91.07, obs. = 84), (for 1990; Gen. 1 two trap values were, EMS = 26.94, obs. = 63; Gen. 5 two trap values were, EMS = 8.11, obs. = 63; Gen. combined two trap values were, EMS = 31.58, obs. = 126; Gen. 1 one trap values were, EMS = 150.2, obs. = 63; Gen. 5 one trap values were, EMS = 11.61, obs. = 63; Gen. combined one trap values were, EMS = 97.38, obs. = 126) (Pooled two year values were, EMS = 31.97, obs. = 329).

[3]Generation.

[4]Method = 1 trap or 2 traps per tree.

Analysis of pooled data for the two years indicated there were significant differences (P=0.01) due to trap height, date, and height by date interaction within years. Apparent differences in total captures between the two years were not significant (Table 6).

Captures of male moths were higher at the 9.14 m level than at 4.57 m during generation 5 in both years. Generally, captures at the 9.14 m height were also greater for both years during generation 1. However, on some dates, traps located 4.57 m above the orchard floor yielded larger numbers. The lack of significant differences in capture except for generation 5 data in 1989 and the pooled data was probably due to large variability within the individual groupings. Capture patterns for both years during generation 1 are presented in Figure 12 and for generation 5 in Figure 13.

One important implication for future IPM efforts was the indication that traps located 9.14 m above the orchard floor captured adult male shuckworms earlier than those located at the lower level. Capture numbers also tended to remain higher for a longer period of time in the 9.14 m traps. Additionally, of 28 males captured during the period of generations 2, 3 and 4, 21 were from 9.14 m traps. Smaller differences due to trap height during generation 1 are not as important to an IPM program as the adults of this generation do little damage to pecans (Moznette et al., 1931, Payne and Heaton, 1975). This lack of differences,

Figure 12. Captures of Adult Male Hickory Shuckworm by Trap Height during Generation One.

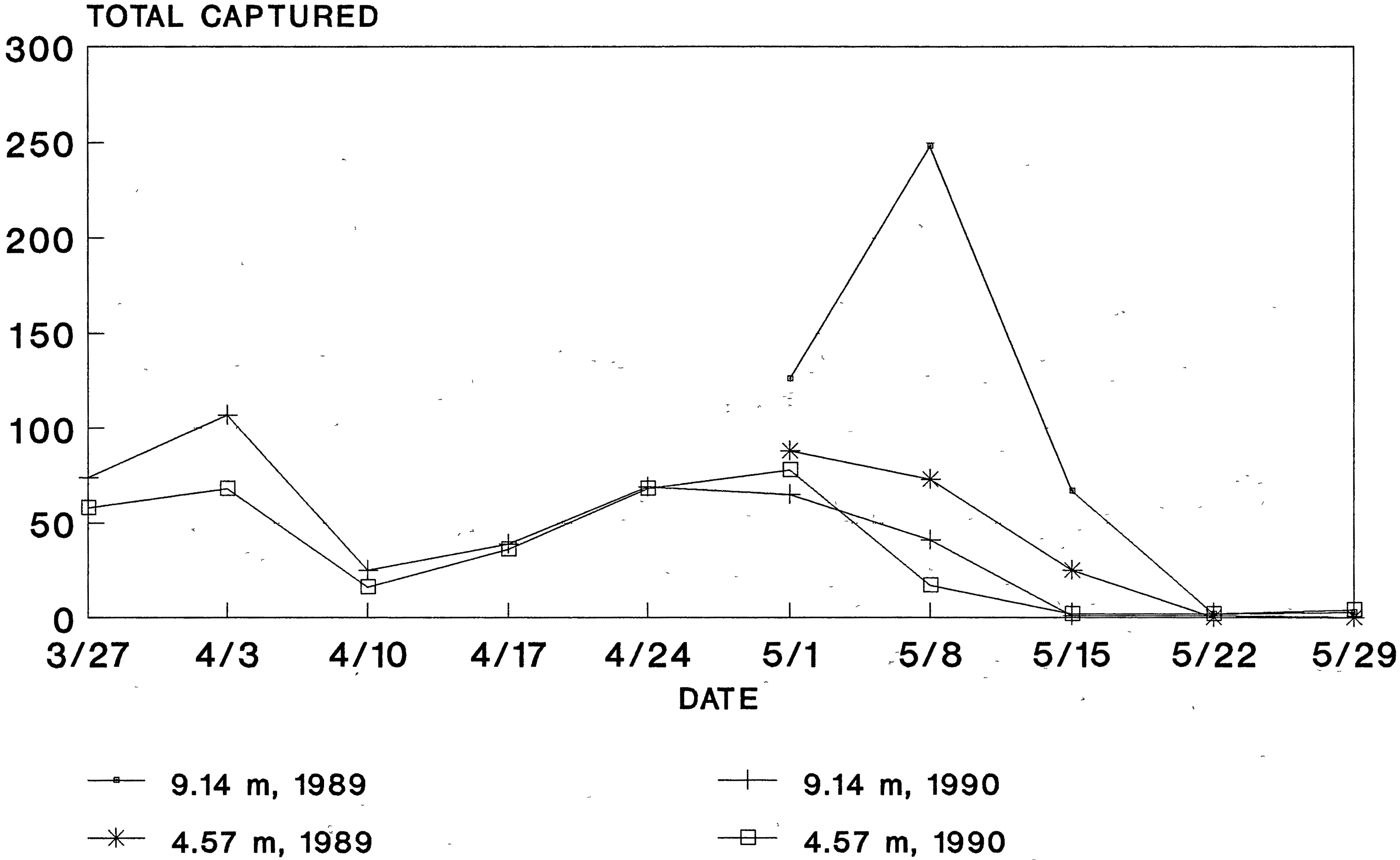
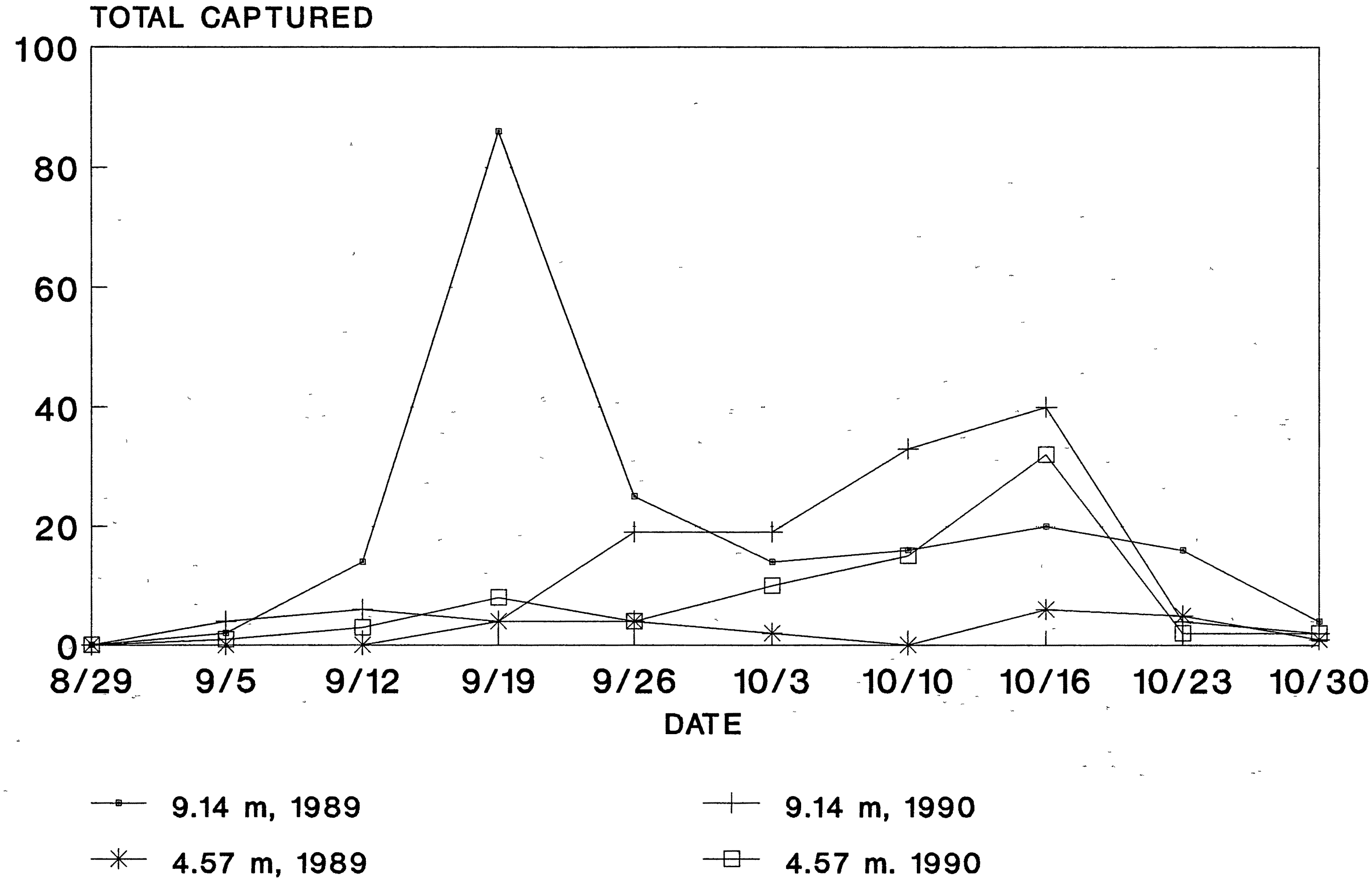

TOTAL CAPTURED
300
250
200
150
100
50
0
3/27
4/3
4/10
4/17
4/24
5/1
5/8
5/15
5/22
5/29
DATE
9.14 m, 1989
9.14 m, 1990
4.57 m, 1989
4.57 m, 1990

Figure 13. Captures of Adult Male Hickory Shuckworm by Trap Height during Generation Five.


TOTAL CAPTURED
100
80
60
40
20
0
8/29
9/5
9/12
9/19
9/26
10/3
10/10
10/16
10/23
10/30
DATE
9.14 m, 1989
9.14 m, 1990
4.57 m, 1989
4.57 m. 1990

however, may be partially explained by the fact that most moths of this generation emerge from shucks on the orchard floor. When attempting to fly, they may be limited by the relatively strong spring breezes common to the Southeast and the lack of protective foliage on the pecan trees. Thus, moths appearing in early spring may not be able to fly as high as those of later generations. Additionally, there is no fruit present at this time to attract them higher into the tree.

It appears that during the more critical times of the season for shuckworm damage, the placement of traps at the higher level would be preferable for IPM implementation. This appears to be true for mass trapping and removal programs, detection of activity levels as a control trigger mechanism, or for determination of precise activity peaks.

Within-Canopy Horizontal Placement

Analysis of Variance indicated no differences due to trap location in the 1989 data (P=0.05). Analysis of data from the spring of 1990 showed decreasing numbers of captures from traps located at the tree center to the midpoint location and to the canopy dripline. Moth captures at the tree center were significantly higher than at the dripline location (ANOVA, LSD: P=0.05) but not for captures at the midpoint location. Competition among traps in each tree should have been high. Means are presented in Table 7.

TABLE 7

EFFECT OF HORIZONTAL PLACEMENT OF TRAPS ON CAPTURE OF HICKORY SHUCKWORM MALES WITH 3 TRAPS PER TREE[1]

		Mean[2] No. Males / Trap / 7-day Period by Generation	
Year	Trap Location	Generation 1	Generation 5
1989	Canopy Center	0.42a	3.17a
	Midway Between Center and Dripline	0.21ab	3.20a
	Canopy Dripline	0.14 b	2.85a
1990	Canopy Center	1.48a	1.56a
	Midway Between Center and Dripline	1.55a	0.93 b
	Canopy Dripline	0.65 b	0.27 c

[1]Each of nine data trees (replications) was equipped with three traps; one each at all three locations.

[2]Means not followed by the same letter in the same column within each year are significantly different (LSD: P=0.05), (values for 1989 were; Gen. 1, EMS = 1.54, obs. = 72; Gen. 5, EMS = 2.01, obs. = 54), (values for 1990 were; Gen. 1, EMS = 15.81, obs. = 63; Gen. 5, EMS = 18.46, obs. = 44).

Data obtained during the late summer and early fall of 1990 presented a clearer picture of locational effects. When the test was redesigned as described previously, main effects due to trap location became obvious. Analyses indicate that traps placed in the tree center consistently captured significantly more shuckworm males than those placed at either of the other locations. Also, traps at the midpoint location captured significantly more than those at the dripline (ANOVA, LSD: P=0.05). This trend was repeated in all comparisons. Only those data where tree center and midpoint locations were compared in the same tree exhibited non-significance at the level, P=0.05. These data were significant at P=0.08, however. Means are presented in Table 8 and Figure 14 presents the overall pattern of male captures for the three trap locations during this phase of the study.

The results indicate that the center of the tree canopy may be the optimum site for C. caryana sex pheromone trap placement. Further, such placement should tend to negate the effect of directional placement discussed previously. The nature of pecan tree growth is such that trap positioning and maintenance are as easy or easier in the canopy center than among outer branches.

TABLE 8

EFFECT OF HORIZONTAL PLACEMENT OF TRAPS ON CAPTURE OF HICKORY SHUCKWORM MALES WITH 1, 2 OR 3 TRAPS PER TREE, 1990

Comparison	Trap Location[1]	Mean[2] No./Trap /7 days	EMS[3]
I	Canopy Center	1.34 ±0.14a	8.91
	Midway Between Center and Dripline	0.70 ±0.12b	
II	Canopy Center	1.56 ±0.20a	31.92
	Dripline	0.34 ±0.12b	
III	Midway Between Center and Dripline	0.79 ±0.07a	11.64
	Dripline	0.07 ±0.04b	
IV	Canopy Center	1.56 ±0.18a	18.46
	Midway Between Center and Dripline	0.93 ±0.18b	
	Dripline	0.27 ±0.09c	
V[4]	Canopy Center	1.50 ±0.25	
	Midway Between Center and Dripline	0.77 ±0.15	
	Dripline	0.23 ±0.07	

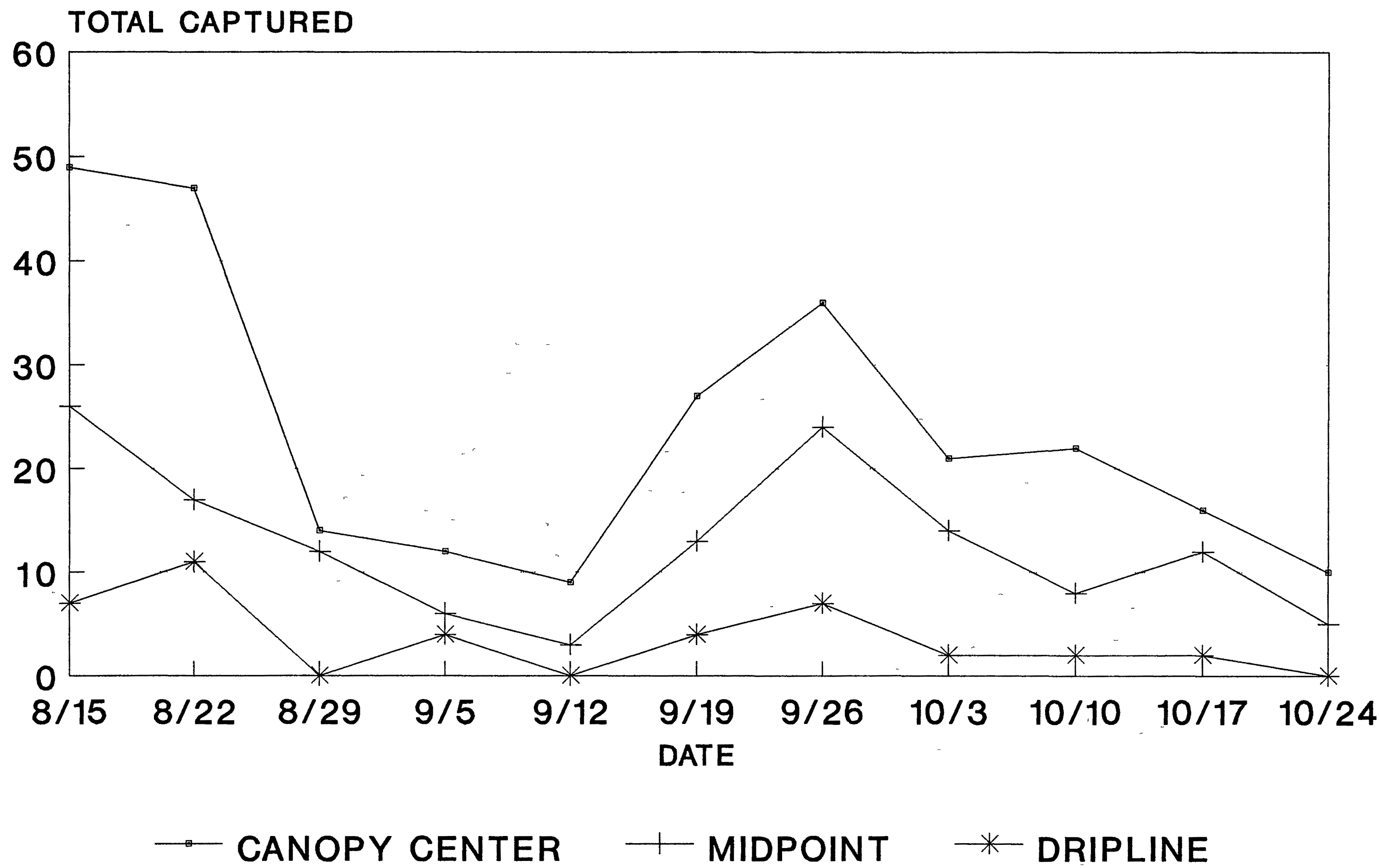
[1]Data compares four replicates of each comparison with 44 observations for each.

[2]Values within comparisons not followed by the same letter are significantly different at the following levels:
I - ANOVA: P=0.08; II - ANOVA: P=0.01;
III - ANOVA: P=0.01; IV - ANOVA, LSD: P=0.05; (0.326).

[3]Error Mean Squared

[4]Data compares four replicates each of trees equipped with a single trap at one of the three locations for informational purposes.

Figure 14. Captures of Hickory Shuckworm Adult Males by Horizontal Location of Trap; Fall, 1990.


TOTAL CAPTURED
60
50
40
30
20
10
0
8/15
8/22
8/29
9/5
9/12
9/19
9/26
10/3
10/10
10/17
10/24
DATE
CANOPY CENTER
MIDPOINT
DRIPLINE

Literature Cited

AliNiazee, M. T., 1983. Monitoring the filbertworm, Melissopus latiferreanus (Lepidoptera: Olethreutidae), with sex attractan traps: effect of trap design and placement on moth catches. Environ. Entomol. 12(1): 141-6.

Bode, W. M., D. Asquith, and J. P. Tette. 1973. Sex attractants and traps for tufted apple budmoth and redbanded leafroller males. J. Econ. Entomol. 66: 1129-30.

Brown, W. M. 1984. Saturation of pheromone sticky traps by Platynota idaeusalis (Walker) (Lepidoptera: Tortricidae). J. Econ. Entomol. 77: 915-18.

Cochran, W. G., and G. M. Cox. 1957. Experimental Designs. John Wiley & Sons, New York. 611 pp.

Danko, L., and G. L. Jubb, Jr. 1983. Field evaluation of pheromone-baited traps for monitoring grape berry moth (Lepidoptera: Olethreutidae). J. Econ. Entomol. 76: 480-3.

David, P. J., and R. L. Horsburgh. 1989. Effects of pheromone trap design, placement, and pheromone dispenser and load on male Platynota flavedana and P. idaeusalis (Lepidopters: Tortricidae) catches in Virginia apple orchards. Environ. Entomol. 18(1): 145-9.

Elkinton, J. S., and R. T. Carde. 1981. The use of pheromone traps to monitor distribution and population trends of the gypsy moth, pp. 41-55. In E. R. Mitchell [ed.], Management of Insect Pests with Semiochemicals. Plenum Press, New York.

Howell, J. F. 1972. An improved sex attractant trap for codling moths. J. Econ. Entomol. 65: 609-11.

Hoyt, S. C., P. H. Westigard, and R. E. Rice. 1983. Development of pheromone trapping techniques for male San Jose scale (Homoptera: Diaspididae). Environ. Entomol. 12(1): 371-5.

Jubb, G. L., Jr., and L. Danko. 1982. Comparison of four trap designs for monitoring grape berry moth, Endopiza viteana. Melsheimer Entomol. Ser. 32: 1-4.

McNally, P. S., and M. M. Barnes. 1980. Inherent characteristics of codling moth pheromone traps. Environ. Entomol. 9(5): 538-41.

Mcnally, P. S., and M. M. Barnes. 1981. Effects of codling moth pheromone trap placement, orientation and density on trap catches. Environ. Entomol. 10(1): 22-6.

Moznette, G. F., T. L. Bissel, and H. A. Adair. 1931. Insects of the pecan and how to conbat them. USDA Farmers Bull. 1954. 59 pp.

Payne, J. A., and E. K. Heaton. 1975. The hickory shuckworm: its biology, effect on nut quality, and control. Annu. Rep. Northern Nut Growers Assoc. 66: 19-25.

Riedl, H. 1980. The importance of pheromone trap density and trap maintenance for the development of standardized monitoring procedures for the codling moth (Lepidoptera: Tortricidae). Can. Entomol. 112: 655-63.

Riedl, H, B. A. Croft, and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological time models. Can. Entomol. 108: 449-60.

Riedl, H., S. A. Hoying, W. W. Barnett, and J. E. Detar. 1979. Relationship of within-tree placement of the pheromone trap to codling moth catches. Environ. Entomol. 8(2): 765-9.

Sanders, C. J. 1978. Evaluation of sex attractant traps for monitoring spruce budworm populations (Lepidoptera: Tortricidae). Can. Entomol. 110: 43-50.

Sanders, C. J. 1986. Evaluation of high capacity, nonsaturating sex pheromone traps for monitoring population densities of spruce budworm (Lepidoptera: Tortricidae). Can. Entomol. 118: 611-19.

SAS Institute Inc. 1988. SAS Procedures Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC. 441 pp.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC. 1028 pp.

Steck, W., and B. K. Bailey. 1978. Pheromone traps for moths: evaluation of cone trap designs and design parameters. Environ. Entomol. 7(2): 449-55.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and Procedures of Statistics. McGraw-Hill, New York. 633 pp.

Taschenberg, E. F., R. T. Carde, A. Hill, J. P. Tette and W. L. Roelofs. 1974. Sex pheromone trapping of the grape berry moth. Environ. Entomol. 3(1): 192-4.

Tedders, W. L., and G. W. Edwards. 1972. Effects of blacklight trap design and placement on catch of adult hickory shuckworms. J. Econ. Entomol. 65: 1624-7.

Wall, C. 1989. Monitoring and spray timing, pp. 39-66. In A. R. Jutsum and R. F. S. Gordon [eds.], Insect Pheromones in Plant Protection. John Wiley & Sons, New York.

Westigard, P. H., and K. L. Graves. 1976. Evaluation of pheromone baited traps in a pest management program on pears for codling moth control. Can. Entomol. 108: 379-82.

Younce, C. E., C. R. Gentry, J. H. Tumlinson, R. E. Doolittle, and D. G. Nielsen. 1976. Lesser peachtree borer: influence of trap height, substrates, concentration and trap design on capture of male moths with females and with a synthetic pheromone. Environ. Entomol. 5(3): 417-20.

Younce, C. E., C. R. Gentry, D. G. Nielsen and F. F. Purrington. 1979. Influence of trap design and placement on captures of lesser peachtree borer and peachtree borer males, pp. 55-66. In J. W. Neal, Jr. [ed.], Pheromones of the Sesiidae. USDA Pub. ARR-NE-6.

CHAPTER IV

RELATIONSHIP OF *Cydia caryana* PHEROMONE TRAP CAPTURES TO FRUIT INFESTATION

Introduction

The use of pheromone trapping in an IPM system may take several forms as discussed Chapter I. The pecan IPM programs now in place utilize treatment thresholds for most foliar pests and some fruit pests (McVay and Ellis, 1979; Ellis et al., 1983; McVay and Strother, 1983). For the hickory shuckworm, these programs presently rely on black-lights for monitoring and triggering of insecticide applications. Due to the difficulties inherent in suspending and operating such traps in a commercial orchard, many producers rely simply on past history and fruit phenology to decide when to apply control measures.

If the sex pheromone of *C. caryana* is to be successfully integrated into an IPM system, the relationship of trap captures to fruit infestation levels must be determined. Research of this nature has been conducted in other orchard crops, especially for the codling moth, *C. pomonella* (L.), in apples (Madsen and Vakenti, 1972; Hagley, 1973;

Madsen and Vakenti, 1973; Riedl and Croft, 1974; Riedl et al., 1976; Vakenti and Madsen, 1976; Rock et al., 1978; Baker et al., 1980). No such research has yet been reported for C. caryana in pecan. The study reported here was conducted to determine if the numbers of male shuckworm moths captured in pheromone traps baited with the species' sex lure could be related to the levels of fruit infestation.

Materials and Methods

In 1989, the study was conducted in a 32.3 ha (80 acre) commercial pecan orchard located in Baldwin Co., AL. The orchard and candidate trees met all criteria described in Chapter III (Materials and Methods; General). On August 15, 20 Stuart pecan trees were each equipped with rope and pulley arrangements and a single Pherocon Ic trap baited with the Scentry, Inc. commercial lure. Traps were monitored at 7-day intervals until Nov. 6. Male shuckworm moths captured were counted and removed on each monitoring date; lures and trap bottoms (liners) were replaced at 28-day intervals.

The timing of this study coincided with the generation 5 activity period of C. caryana previously discussed. This generation was chosen for the study bercause fruit infested by larvae during this time remain on the tree; fruit entered by larvae of earlier generations abscise (Smith, 1985; McVay and Estes, 1989). No pesticide was applied to the trees for control of any insect or mite pest during the study.

On Nov. 11, the fruit (pecans) on each tree were shaken to the ground with a shock-wave type commercial tree shaker. The area under the tree canopy was divided into four quadrants. Demarcation of the quadrants corresponded to the four cardinal directions on line from the dripline to the tree trunk. A total of 25 pecans, both with and without shucks, was picked at random from each quadrant. Samples from all four quadrants were combined into a 100-pecan sample for each tree. Each pecan was inspected for indications of shuckworm infestation. Yield was not obtained for each tree but the average yield determined.

Due to a scarcity of crop in the orchard utilized in 1989, the study was relocated in 1990. This orchard was located in Mobile Co., AL, and was ca. 40 km (25 miles) west of the original study site on the same latitude. This orchard consisted of ca. 16.2 ha (40 acres) of mature pecan trees which met all criteria previously discussed. Fifteen data trees were selected at random and baited traps were installed on Aug. 15, 1990. Monitoring and data collection were as described above, except they were terminated on October 31. Lures and liners were replaced every 28 days and no peaticide was applied to the data trees.

Trees were shaken on Nov. 3, 1990, and samples were taken as in 1989. Again, individual tree yields were not taken but an average for all data trees was determined. Data were analyzed by Pearson's Correlation Coefficient and Liner Regression to determine any relationship between trap captures and levels of infestation (Steel and Torrie, 1980; SAS Institute, 1988; SAS Institute, 1988b).

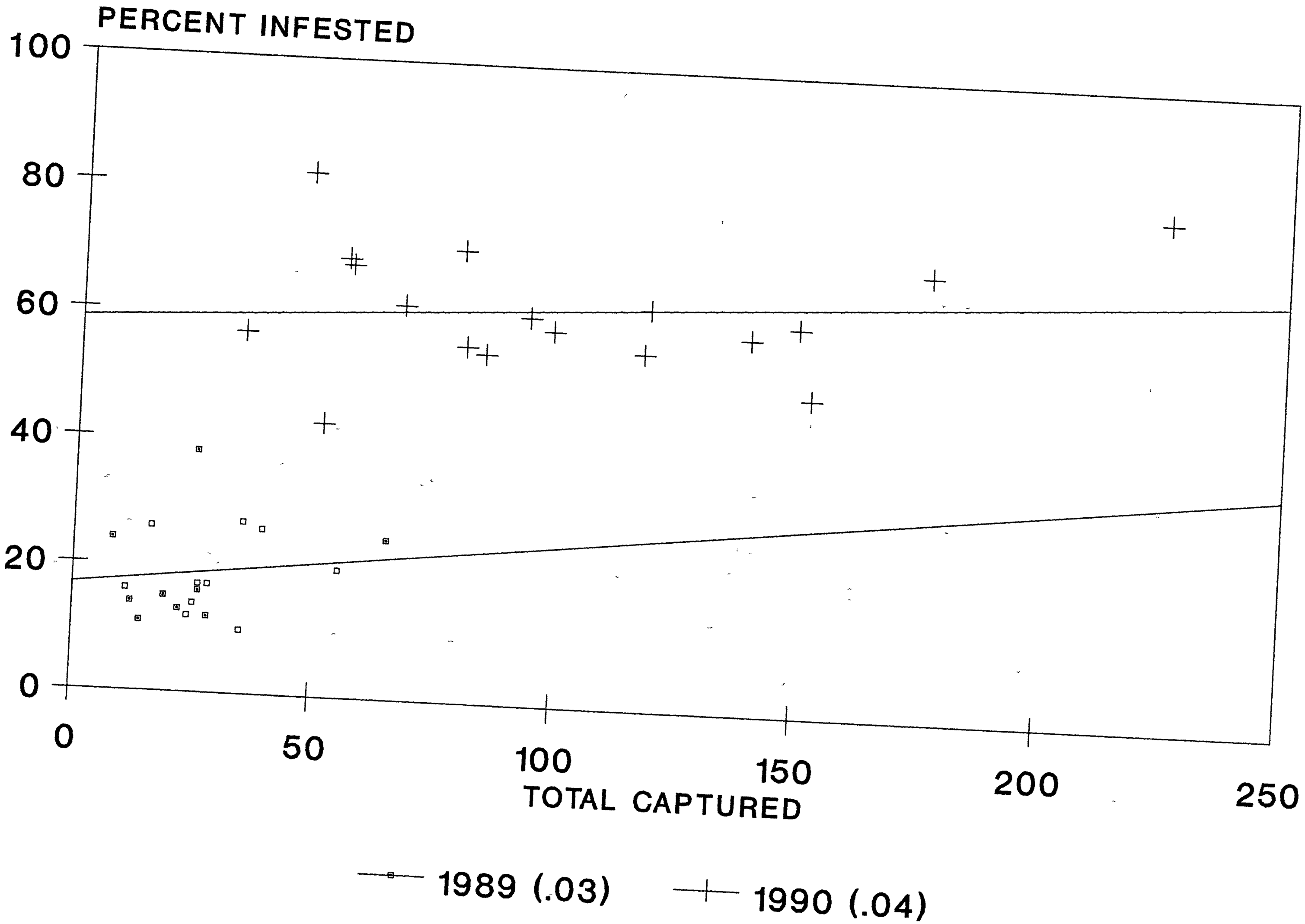
Results and Discussion

Pearson's Correlation Coefficient of total male shuckworm captures with levels of fruit infestation were 0.17 and 0.19 for 1989 and 1990, respectively (P=0.4). Linear Regression indicated a positive but non-significant relationship between total captures and level of infestation. For 1989 and 1990 data respectively, R^2 values were 0.03 and 0.04. These low values were probably due to variation (Figure 15).

These analyses indicate that, although there was a positive correlation between the numbers of male hickory shuckworms captured and the levels of fruit infestation, i.e., infestation rates rise with increased numbers of males captured, total capture was not a very accurate estimator of infestation level.

The regression lines of both years were similar (Fig. 15). The differences between location were due to the variation in crop load and shuckworm activity levels. In 1989, (Baldwin Co.) trees averaged 34 kg (ca. 75 pounds) of pecans and shuckworm activity was not extremely heavy. Conversely, in 1990, (Mobile Co.) trees averaged 15.9 kg (ca. 35 pounds) of pecans and shuckworm activity was greater.

Figure 15. Regressions Depicting the Relationship of Pheromone Trap Capture of Male Hickory Shuckworm to Fruit Infestation Levels (R^2 was equal to 0.03 in 1989 and 0.04 in 1990).


PERCENT INFESTED
100
80
60
40
20
0
0
50
100
150
200
250
TOTAL CAPTURED
1989 (.03)
1990 (.04)

These data indicate that traps baited with the sex pheromone of C. caryana may not provide an accurate indicator of potential damage by the hickory shuckworm when used alone. When these results are considered along with seasonal activity trends determined by the pheromone traps (Chapter II), it appears that sex pheromone baited traps are not very useful for pecan IPM systems other than to indicate presence of the insect species at this time.

Literature Cited

Baker, T. C., R. T. Carde, and B. A. Croft. 1980. Relationship between pheromone trap capture and emergence of adult oriental fruit moths, _Grapholitha molesta_ (Lepidoptera: Tortricidae). Can. Entomol. 112: 11-15.

Ellis, H. C., P. Bertrand, M. French, and C. Bruce. 1983. Pecan pest management in Georgia, pp. 89-100. _In_ J. A. Payne [ed.], Pecan Pest Management - Are We There? Misc. Pub. Entomol. Soc. of Am. 13(2).

Hagley, E. A. C. 1973. Timing sprays for codling moth (Lepidoptera: Olethreutidae) control on apple. Can. Entomol. 105: 1085-89.

Madsen, H. F., and J. M. Vakenti. 1972. Codling moths: female-baited and synthetic pheromone traps as population indicators. Environ. Entomol. 1(5): 554-7.

Madsen, H. F., and J. M. Vakenti. 1973. Codling moth: use of codlemone-baited traps and visual detection of entries to determine need of sprays. Environ. Entomol. 2(2): 677-9.

McVay, J. R., and H. C. Ellis. 1979. Extension approaches to pecan pest management in Alabama and Georgis, pp. 121-49. _In_ D. J. Boethel and R. D. Eikenbary [eds.], Pest Management Programs for Deciduous Tree Fruits and Nuts. Plenum Press, New York.

McVay, J. R., and G. R. Strother. 1983. Evolution and status of pecan pest management in Alabama, pp. 101-10. _In_ J. A. Payne [ed.], Pecan Pest Management - Are We There? Misc. Pub. Entomol. Soc. of Am. 13(2).

McVay, J. R., and P. M. Estes. 1989. Insect and mite pests. pp. 105-25. _In_ W. D. Goff, J. R. McVay and W. Gazaway [eds.], Pecan Production in the Southeast: a guide for growers. Ala. Coop. Ext. Ser. Pub. ANR-459, Auburn Univ.

Riedl, H., and B. A. Croft. 1974. A study of pheromone trap catches in relation to codling moth (Lepidoptera: Olethreutidae) damage. Can. Entomol. 106: 525-37.

Riedl, H., B. A. Croft, and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological-time models. Can. Entomol. 108: 449-60.

Rock, G. C., C. C. Childers, and H. J. Kirk. 1978. Insecticide applications based on codlemone trap catches v. automatic schedule treatments for codling moth control in North Carolina apple orchard. J. Econ. Entomol. 71(4): 650-3.

SAS Institute Inc. 1988. SAS Procedures Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC. 441 pp.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Cary, NC. 1028 pp.

Smith, M. T. 1985. Characterization of the hickory shuckworm, Cydia caryana (Lepidoptera: Tortricidae: Olethreutinae), sex pheromone: Electrophysiological, behavioral, chemical and field analysis. Ph.D. dissertation, Okla. St. Univ. 137 pp.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and Procedures of Statistics. McGraw-Hill, New York. 633 pp.

Vakenti, J. M., and H. F. Madsen. 1976. Codling moth (Lepidoptera: Olethreutidae): monitoring populations in apple orchards with sex pheromone traps. Can. Entomol. 108: 433-8.

CHAPTER V

SUMMARY DISCUSSION

This research was designed to explore the usefulness of the sex pheromone of the hickory shuckworm, C. caryana, for integration into pecan IPM systems. Additionally, development of specific parameters for orchard use of the pheromone was necessary for any future efforts. The results of this effort have examined several of those parameters as well as indicating the general usefulness of the pheromone to research. Just as importantly, the results have also indicated the need for more information about the basic biology and habits of the hickory shuckworm.

As discussed in detail in the preceeding chapters, the occurrence of a bimodal emergence pattern for the over-wintering generation of the shuckworm was documented in the Southeast and the pheromone baited trap proved effective as a monitoring tool for daily flight activity. Additionally, the results have shown that trap type and location have a definite bearing on trap efficacy.

One of the more intriguing avenues possible for future research is that into the possibility of a relatively powerful plant karimone that may mediate much of the shuckworm adult's behavior. The presence of such a behavior modifying chemical may be one of the reasons for difference in trap efficacy due to location. The study of cardinal direction effects indicated that traps on the north and east facings of the tree capture more insects than those on the south or west in a region where southwest breezes predominate. The captured moths may have been responding to the plant karimone first and the pheromone secondarily, once within the tree canopy. The same may be true for the height and horizontal locational effects. A mature pecan tree produces the bulk of its crop in the upper portions of the canopy. It was commonly observed that more shuckworm moths were captured in trees with a substantial crop load than in one with little or no crop, regardless of the previous year's capture number or crop load for any specific tree. The capture of larger numbers of shuckworm moths in blacklight traps in trees with a crop as opposed to no crop has been documented (Tedders and Edwards, 1972). Regardless, the results of studies involving the effects of trap type, directional placement, trap height, and horizontal location should prove valuable to future research efforts utilizing this pheromone. Simply knowing where to place a trap and what type of trap to use will save much time and confusion.

As to the specific integration of the sex pheromone into IPM programs, the results presented here indicate a somewhat limited usefulness. The pheromone-baited traps failed to delineate a great deal of activity during generations 2, 3, and 4 of the shuckworm, which are the most damaging generations of this insect (Moznette, 1938; Osburn et al., 1963; Payne and Heaton, 1975). Possibly, the extensive damage during these generations is due to immigration of previously mated individuals from foci in native hickories or wild pecans. Such individuals may not be as attracted to a trap baited with sex pheromone. Tedders and Edwards (1972) reported that the great majority of both sexes captured during the summer months in blacklight traps had been previously mated.

This information, when considered with the lack of significant correlation between trap captures and infestation levels reported in Chapter IV, indicates a limited role for the pheromone in IPM systems at present. Certainly, it can be useful for surveys to determine the potential for shuckworm problems, and traps baited with the lure can be quite effective as a quarantine tool (Wall, 1989).

Timing of treatments based on numbers of males captured may not be practical at the present time. Additional research is needed on combining pheromone trapping with other sampling methodology and physiological-time models as has been reported for other Tortricid species (Riedl et al., 1979; Wall, 1989). Indications are that such efforts will also need to include development of sampling systems that provide a reasonably accurate picture of the crop load on the pecan tree as early as 12 to 16 weeks prior to harvest.

This pheromone may show promise for mass trapping and removal of the moths of the overwintering generation with the possibility of reducing damage due to subsequent generations (Bakke and Lie, 1989). Use as a mating disruptant (Campion et al., 1989) may also be possible in areas where commercial pecan orchards are the only available host for the species or if the foci of mating activity can be determined. Both of these avenues warrant investigation.

Literature Cited

Bakke, A., and R. Lie. 1989. Mass trapping, pp. 67-87. In A. R. Jutsum and R. F. S. Gordon [eds.], Insect Pheromones in Plant Protection. John Wiley & Sons, New York.

Campion, D. G., B. R. Critchley, and L. J. McVeigh. 1989. Mating disruption, pp. 89-119. In A. R. Jutsum and R. F. S. Gordon [eds.], Insect Pheromones in Plant Protection. John Wiley & Sons, New York.

Moznette, G. F. 1938. Some important biological factors in the control of the hickory shuckworm on pecan. Proc. S. E. Pecan Growers Assoc. 32: 11-4.

Osburn, M. R., W. C. Pierce, A. M. Phillips, J. R. Cole, and G. L. Barnes. 1963. Controlling insects and diseases of the pecan. USDA Agric. Handb. No. 240, 55 pp.

Payne, J. A., and E. K. Heaton. 1975. The hickory shuckworm: its biology, effect on nut quality, and control. Annu. Rep. Northern Nut Growers Assoc. 66: 19-25.

Riedl, H., B. A. Croft, and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological-time models. Can. Entomol. 108: 449-60.

Tedders, W. L., and G. Edwards. 1972. Effects of blacklight design and placement on catch of adult hickory shuckworms. J. Econ. Entomol. 65(6): 1624-7.

Wall, C. 1989. Monitoring and spray timing, pp. 39-66. In A. R. Jutsum and R. F. S. Gordon [eds.], Insect Pheromones in Plant Protection. John Wiley & Sons, New York.

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