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THE BIOLOGY AND CONTROL OF THE PINE CANDLE MOTH, *Exoteleia nepheos*, ON SCOTCH PINE IN MICHIGAN

By

Fred Paul Hain

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ABSTRACT

THE BIOLOGY AND CONTROL OF THE PINE CANDLE MOTH, *Exoteleia nepheos*,[1/] ON SCOTCH PINE IN MICHIGAN

By

Fred Paul Hain

The pine candle moth,[2/] *Exoteleia nepheos*, poses a serious threat to plantation and ornamental pines. It mines in Scotch pine needles during the early stages of larval development and enters the bud during the first flush of spring growth, thereby destroying the tree's aesthetic appearance and value as a Christmas tree. Heavily attacked trees are severely stunted and eventually die. Adults are active from mid-June to mid-August, ovipositing in needle sheaths or along twigs. Eggs hatch in about 10 days with larvae overwintering in the needles where high winter mortality may occur. Parasitism by *Copidosoma deceptor* Miller (Encyrtidae) is an important biological factor in controlling *E. nepheos*. Approximately 37.63% of the population in one Michigan stand was parasitized and about 80% of this was by *C. deceptor*. Peak emergence of the pine candle moth will occur 1060 ± 32 degree days above 52° F. threshold temperature. Insecticides, parasites, pheromones and host resistance were investigated for their potential use in an integrated control program. Guthion®, diazinon and

methoxychlor gave excellent control but Meta-Systox-R® had the least effect on the parasites of the pine candle moth while significantly reducing the pest population. Granular systemics applied to the soil were ineffective in controlling the pest. A pheromone, produced by the females and attracting the males, was discovered and found most effective at distances of 3 m. or less. But in a screening test of various chemical materials, the actual compound could not be identified. Attempts to investigate host resistance within varieties of Scotch pine were not successful as the artificial experimental techniques were not conducive to establishing any attack pattern.

1/ Lepidoptera:Gelechiidae

2/ Common name accepted by the Entomological Society of America for *Exoteleia nepheos*, 7 February 1972.

ACKNOWLEDGEMENTS

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INTRODUCTION

The pine candle moth, *Exoteleia nepheos* Freeman, is a recently discovered pest of Michigan plantation pines. Its main host is Scotch pine, *Pinus sylvestris* L., but it also occurs on red pine, *P. resinosa* Aiton, Austrian pine, *P. nigra* Arnold, and Mugho pine, *P. mugo* Turra (Freeman, 1966). The complete range of the pest is not known but it is also present in Ohio (Neiswander, 1966), and Toronto and Ottawa, Canada (Lindquist and Trinnell, 1967). There is very little information in the literature in regards to its life history, biology, or control. In Michigan it appears to be spreading throughout the southern half of the lower peninsula, attacking mainly Christmas tree plantations of Scotch pine. However, since it is also found on trees 10 to 25 feet tall (Lindquist and Trinnell, 1967), it must be considered a possible threat to forest trees as well.

The overall objective of the study was to learn the pest's habits and life cycle and to use this information in developing a management program that would not be injurious to the environment. With the present concern over environmental contamination by pesticides a chemical that would require repeated applications to suppress the pest population is not desirable. Therefore a further objective was to determine what influence certain chemicals had on the entire environmental complex and how we could best operate within these conditions to control the pest problem with a minimum of pesticide usage.

The research on the biology and life history of the pine candle moth indicated the potential and necessity of an integrated control program. The following facts about the pest and host, influenced the approach of the present investigations: (1) More than 20 varieties of Scotch pine have demonstrated differences in susceptibility to attack by several insects (Wright, et al., 1966; Wright, et al. 1967; Wright and Wilson, 1972); (2) A high percentage of the bud infesting larvae are parasitized which may serve as an important biological factor in controlling the pine candle moth (Campbell and Balderston, 1971; Lindquist and Trinnell, 1967; Neiswander, 1966); (3) Adult females produce a pheromone that attracts males, and pheromones have been used in the past as a surveillance technique to detect the presence of a pest (Steiner, et al., 1961). Besides the life history studies, then, the following studies were made to learn their potential in an integrated control program: (1) pesticides and their effect on parasitism, (2) attraction by natural and synthetic pheromones, and (3) host resistance between varieties of Scotch pine.

LITERATURE REVIEW

Biology

Exoteleia nepheos was first described by Freeman (1967) and a companion paper by Lindquist and Trinnell (1967) briefly describes the biology of the pest in Canada. Adult flight occurs from early July to early August. Females lay their eggs singly or in small clusters on needle sheaths of the previous year's foliage or under bark scales of twigs. The larvae mine along the edges of the needles and overwinter in the needle mines. Mining terminates in mid to late May, when the larvae migrate and feed in staminate flowers or elongating buds. Pupation occurs about mid-June in the flowers or shoots and the moths emerge in about 2 weeks. There are 5 larval instars.

Parasitism plays a major role in the biology of *E. nepheos*. Lindquist and Trinnell (1967) collected the following parasites on *E. nepheos*: *Achrysocharis* sp. (Eulophidae), *Copidosoma geniculatum* (Dalman) (Encyrtidae) and *Eurytoma* sp. (Eurytomidae). Martin (1959) also found a number of parasites on a related host, *E. dodecella* L. Neiswander (1966) found that 43% of the larvae in 2 Ohio counties were parasitized by *C. deceptor*; and Martin (1959) found 50% of the larval population of *E. dodecella* (pine bud moth) in two Ontario plantations parasitized.

Insecticides

Campbell (1968) and Campbell and Balderston (1971) are the only researchers who have tried chemical control on E. nepheos. In a preliminary experiment Campbell (1968) found that Meta-Systox-R® apparently reduced the pine candle moth population by less than 50% while having little effect on the parasites. In an integrated control experiment on Scotch pine in Ohio (Campbell and Balderston, 1971) to control the pine candle moth, the European pine sawfly, Neodiprion sertifer (Geoffroy), and the spotted pine aphid, Eulachnus agilis (Kaltenbach), Meta-Systox-R® was applied in early May while the larvae of E. nepheos were boring in the buds. This did not reduce the number of larvae infesting the candles but did reduce the number of needle mining larvae of the ensuing generation. Furthermore, parasitism of the larvae was not lessened by this treatment. Meta-Systox-R® has also been observed to be an effective control of cone insects on Douglas fir (Hedlin, 1966; Johnson and Zingg, 1967), the walnut aphid (Hefferman; 1967), various aphids on ash and elm, and the elm leaf beetle (Koehler and Campbell, 1968).

Other systemics that have shown activity in pine include Temik® (Kearby, et al., 1970), Di-Syston®, Furadan® and Cygon®. Temik has been found effective against the Saratoga spittlebug on red pine (Wilson and Kennedy, 1971) and is more effective than Di-Syston® in controlling certain aphids on Scotch pine (Kearby and Bliss, 1969). Furadan® has also been used successfully against the Saratoga spittlebug (Wilson and Kennedy, 1971) as well as the pinyon stunt needle midge (Brewer, 1972)Cygon®,n® is a successful control agent of cone insects on Douglas fir (Hedlin, 1966; Johnson and Zingy, 1967) and the western pine tip moth on ponderosa pine (Haverbeke, 1971).

Reynolds and Metcalf (1962) theorize that water solubility and soil mositure play an important role in the effectiveness of granulated systemics applied to the soil. Compounds of extremely low water solubility may move too slowly into the root zone to obtain optimum insecticidal value; conversely, readily soluble compounds may lose their effectiveness more quickly by widespread movement in the soil and thus become lost to the root zone. For example, Di-Syston® took two or more weeks longer to produce cabbage aphid mortalities obtained in a few days with Cygon®.

Attractants

Chemical attractants in detection and control of insect pests offer a promising means of reducing pesticide contamination of the environment (Beroza, 1971). This approach takes advantage of specialized organs which guide insects to food, a mate, or to a place of oviposition. Many of these attractants are highly specific and traps can be baited with them for insect detection. These traps tell where and when an insect is present and help reduce the needless spread of insecticides into areas where the pest is absent.

Roelofs and Comeau (1970) discovered new sex attractants for 37 lepidopterous species in field screening tests with 26 monounsaturated long-chain acetates and alcohols. Systematic screening tests were made practical by the development of long-lasting polyethylene wicks (Glass et al., 1970), which release chemicals for several months at a low rate, and by the availability of economical fold-up, sticky-coated traps (3M Co.).

Some of these attractions can be very strong. Daterman and McComb (1970) found the attractant of the European pine shoot moth, *Rhyacionia buoliana* (Schiffermaller), to be effective over a distance of 86m where 11.5% of the released males where captured in traps baited with females. However, the incidence of male sexual response depended upon the length of time males were conditioned at high illumination (Daterman, 1972). The longer the males were exposed to high illumination (up to 48 hours) the greater was the response to the sex pheromone.

Host Resistance

Host resistance to attack by various insect pests has been exhibited in a number of *Pinus* sp.. Wright, et al. (1966 and 1967) observed four plantations that had 108 seedlots each of *P. sylvestris* infested with the European pine sawfly, *N. sertifer*. They found that the percentage of trees attacked varied from 0 to 6 for north Eurasian varieties, 6 to 11 for south European varieties, and 12 to 26 for central European varieties. Generally, the tallest varieties were attacked most heavily, with the exception of var. *uralensis* which was attacked much less than expected for its height. Compared with other varieties, it has wider needles, a lower foliage concentration of N, P, Na, Mg, Pe, and B, and the larvae feeding on var. *uralensis* were 1/2 to 1 instar behind in development. However, in an artificial feeding experiment with late-instar larvae in the laboratory, no preference was shown between varieties. In a field analysis of pine root collar weevil, Hylobius radicis Buch., resistance between varieties was statistically significant (Wright and Wilson, 1972).

Bennett (1954) reported a host resistance factor with the pine needle miner, Exoteleia pinifoliella (Cham.), attacking various species of host trees. He found a correlation between the internal structure of a pine needle and its susceptibility to injury. Of the many species this pest attacks, lodgepole pine and jack pine were the most favored. The needles of these 2 species have only 2 moderate-sized resin canals located in each corner of the needle. Scotch pine, on the other hand, was definitely undersirable as a host tree, with conspicuous resin canals varying from 6 to 16; the higher the number, the greater the resistance to the insect apparently due to the copious resin flow.

BIONOMICS OF THE PINE CANDLE MOTH

The potential economic impact of the pine candle moth is severe; reducing the aesthetic appearance and value of harvestable Christmas trees, and slowing the growth rate of younger stock. Since the insect presents a major threat to plantation and ornamental pines in Michigan (Fig. 1.), and little is known of its habits and natural controls, investigations were essential. This section reports on the life history and biology of *E. nepheos*, including damage characteristics and degree of parasitism.

Materials and Methods

Three Scotch pine plantations infested with the pine candle moth in lower Michigan were selected for study; one each in the western (West Olive), central (East Lansing), and eastern (Mayville) regions of the State. Each site consisted of approximately 5 acres; the trees were generally 5-7 feet tall with a basal diameter of 2-4 inches. Adult emergence data were collected from these sites in 1969 (West Olive and East Lansing), 1970 (West Olive) and 1971 (West Olive, East Lansing and Mayville). Adults in flight were collected by use of a rotary black-light trap (West Olive and East Lansing), and by pheromone traps (Mayville) which consisted of adults caged in pint sized ice cream cartons with screening on both ends. Cartons were sprayed with Tangle-foot® and placed in the field. Various numbers of males and females were placed within the cartons but

Fig. 1. Michigan counties with known infestations of the pine candle moth (1971).

attraction was best where there was a preponderance of females. The black light traps ran from 8 p.m. to 8 a.m. Climatological data were gathered at each site with a hydro-thermograph. Parasites were collected at West Olive, reared in an insectary at Michigan State University and sent to the USDA Entomology Research Division for identification. Rearing was accomplished by collecting infested buds in late May or early June and placing the material in screen cages. The data collected for larval development came from infested needles and buds in the West Olive plantation.

Life History and Damage

The life history of the pine candle moth in Michigan is similar to that in Ontario, Canada as reported by Lindquist and Trinnell (1967). There is only one generation per year (Fig. 2). In Michigan, adult activity occurs somewhat earlier than in Ontario; adults are found from mid-June to mid-August within the vicinity of the host tree. They are weak flyers and dispersal is probably through infested nursery stock. The adults (Fig. 3A) are a golden brown with 3 grayish and white transverse fasciae on their fore-wings (Freeman, 1967). They have a mean ($\pm$ S.D.) wingspan of 9.23 $\pm$ .47mm and a length of 5.5 $\pm$ .35mm (based on measurements of 50 insects). After mating the females oviposit in needle sheaths or along the twigs (Fig. 3B and 3C); the eggs are laid singly or in small groups of 2-4 and are a light brown, 0.26 $\pm$ .02mm wide and 0.37 $\pm$ .01mm long. The larvae hatch in about 10 days and begin to excavate needle mines

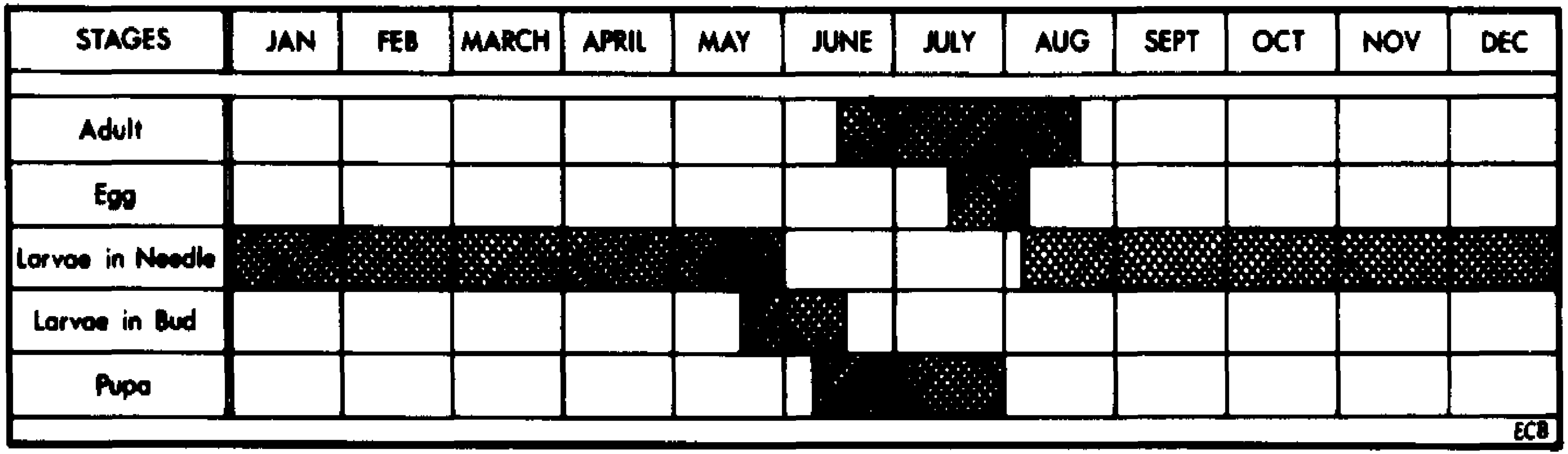

Fig. 2. Seasonal development of the pine candle moth in Michigan.
Ottawa County, 1969-72

Fig. 3. A-I. Stages, damage and parasitism of the pine candle moth: A, adult; B, eggs on needle sheath; C, egg on bark of shoot; D, larvae entrance hole on [illegible] shoot; E, candle opened to show larva; F, candle opened to show pupa [illegible] degrees of injury; H, I, larva parasitized by Copidosoma deceptor.

in the current year's foliage; winter is passed in the needles and excavation continues in the early spring. About the middle of May the larvae transfer to newly developing buds where they resume boring (Fig. 3D and 3E). Pupation occurs within the bud (Fig. 3F) from early June through July. The pupae are about 4.50 ± .06mm long.

The pine candle moth appears to have 5 larval instars. Measurements of over 200 head capsule widths and lengths (Figs. 4 and 5) produced sizes similar to those of Lindquist and Trinnell (1967). Table 1. shows a comparison of the observed head capsule widths with the calculated widths according to the theory of geometric progression (Dyar, 1890), and also shows the figures calculated by Lindquist and Trinnell (1967), which are similar, except for some variation in the fifth instar.

Table 1. Head capsule width measurements of _Exoteleia nepheos_ larvae.

Instar	Head Capsule Widths (mm.)		
	Calculated	Observed	L&T*
I	0.143	0.143	0.136
II	0.187	0.187	0.190
III	0.244	0.246	0.260
IV	0.318	0.315	0.355
V	0.415	0.515	0.485

* Lindquist and Trinnell (1967).

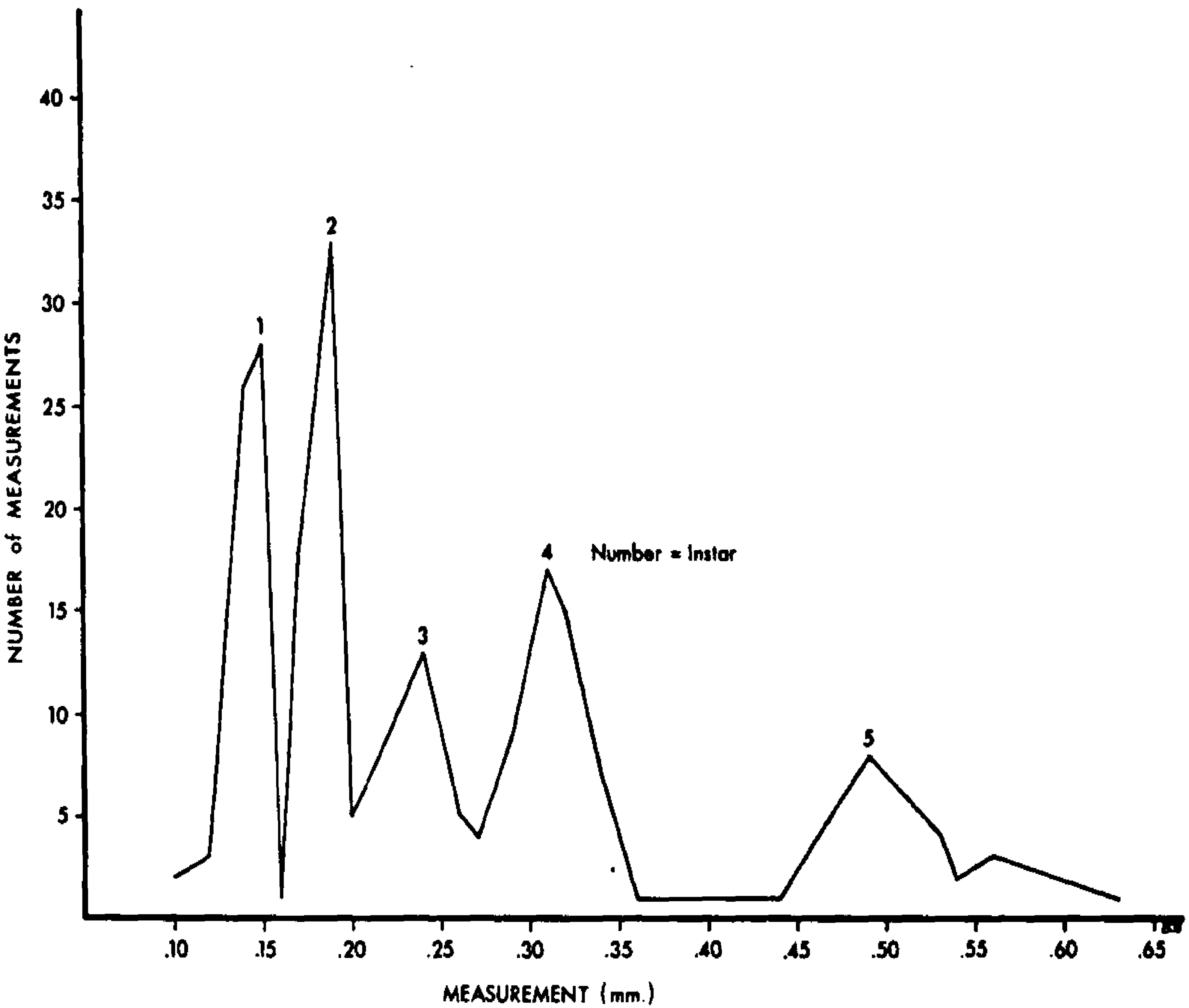

Fig. 4. Head capsule widths of

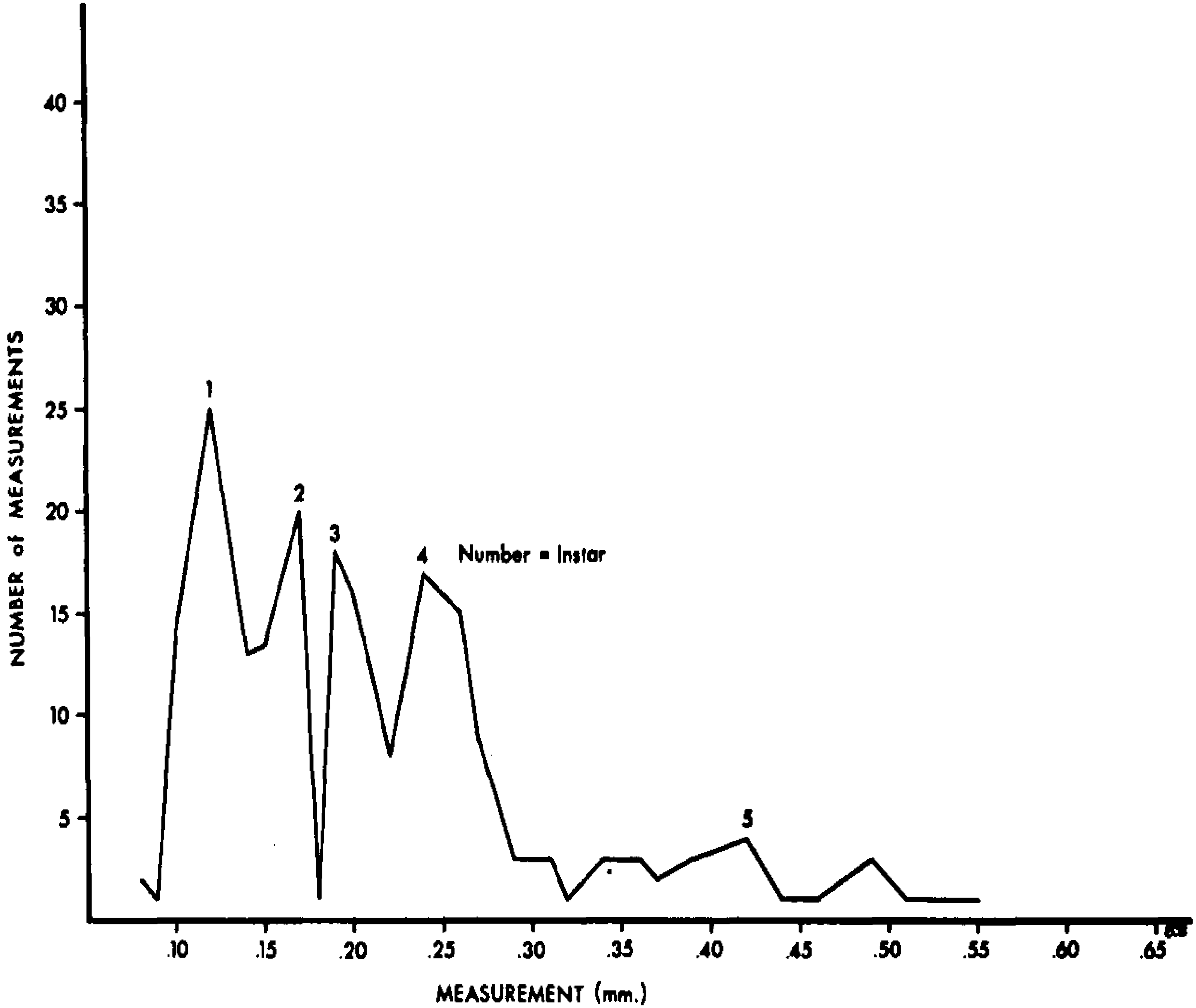

Fig. 5. Head capsule lengths of 203 larvae of the pine candle moth.

The larvae which are a pale yellow brown, overwinter as a 3rd or 4th instar and are in the 5th instar by mid-May. As development progresses the larvae increase in length from 0.5-1.0mm as 1st instar, to as much as 9.0mm for 5th instars. The length of the needle mine also increases from approximately 3.0mm to as much as 48.0mm. Lindquist and Trinnell (1967) state that in the spring the larvae vacate the mine and enter the same needle at a lower point, or an adjacent needle. Therefore, the length of the mine (Appendices Ia and Ib) depends upon whether the larva remains in the needle or transfers to another.

Sex ratio of the emerging adults varies throughout the season but the average ratio during 1971 was 1.92♀:1.00♂. During the early stages of emergence males predominate (Fig. 6), but as the season progresses the females become more abundant, especially when the number of emerging moths is high.

The browning needles caused by the mining activities of *E. nepheos* is inconsequential compared to the serious effects of bud damage. If the infestation is severe, the dead candles (elongating shoots) which are frequently crooked, and the resulting tufted appearance of the foliage along with the distorted tree shape may make the tree unmarketable. Fig. 3G shows the extent of damage that may occur to the candles; the larvae frequently bore 2 or 3 inches into the shoot, but other times only the shoot tip is brown. Even mature Christmas tree stands with light infestations present a hazard as a brood source. For example, in one lightly attacked stand, there was no dramatic alteration in the sale value of the individual

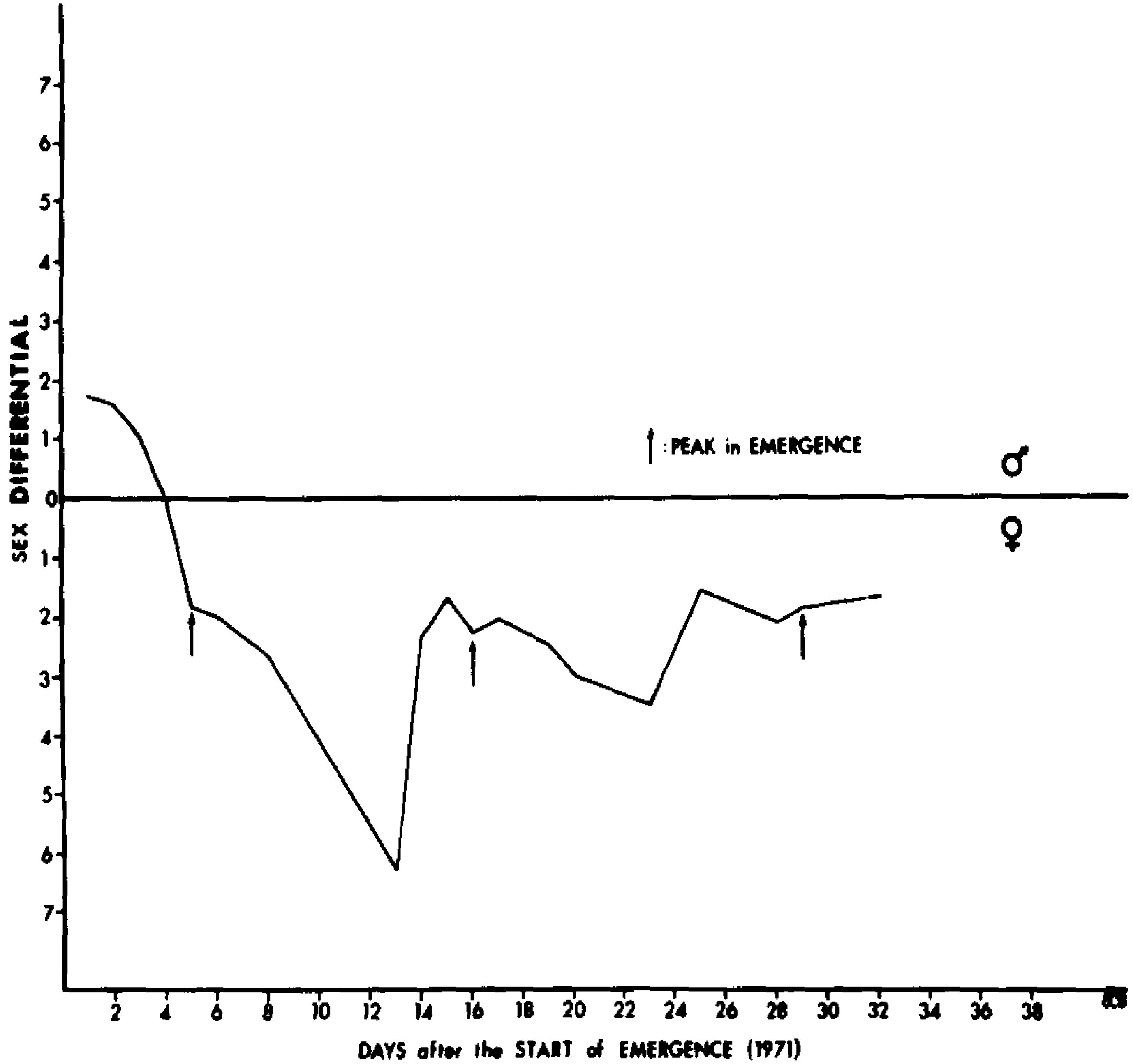

Fig. 6 Sex differential of <u>Exoteleia nepheos</u>. The horizontal line marked 0 indicates no difference in the number of emerging adults (a 1:1 sex ratio.).

trees. However, adjacent to this stand was a 3 year old planting which became infested. In a sample of 25 young trees, 25.5% of the candles were attacked with a range of 0 to 80%. Therefore, due to an obvious reduction in growth rate and tree form, a slight nuisance in a mature stand becomes a serious economic threat in a younger one.

Parasitoids

The following parasites, reared at Michigan State University from material collected at West Olive, Michigan, were identified by the USDA Entomology Research Division, Beltsville, Maryland.[3/]

Exeristes comstockii (Cr.) (Ichneumonidae)

Scambus hispae (Harr.) (Ichneumonidae)

Itoplectis conquisitor (Say) (Ichneumonidae)

Campolex sp. (Ichneumonidae)

Chelonus recurvariae McComb (Braconidae)

Bracon gelechiae Ashm. (Braconidae)

Phanerotoma sp. (Braconidae)

Apanteles paralechiae Mues. (Braconidae)

Copidosoma deceptor Miller (Encyrtidae)

Elasmus setososcutellatus Crawford (Eulophidae)

Sympiesis stigmatipennis Girault (Eulophidae)

Eupelmella vesicularis (Retz.) (Eupelmidae)

3/ Ichneumonidae identified by R. W. Carlson, Braconidae by P. M. Marsh, Syrphidae by L. V. Knutson, and Encryrtidae, Eulophidae, Eupelmidae, Pteromalidae and Eurytomidae by B. D. Burks.

Habrocytus phycidis Ashm. (Pteromalidae)

Eurytoma pini Bugbee (Eurytomidae)

Allograpta obliqua (Say) (Syrphidae)

Lindquist and Trinnell (1967) also collected a species of _Achrysocharis_ (Eulophidae) parasitizing _E. nepheos_ and Martin (1959) found _Pimplopterus parvus_ (Cress.) (Ichneumonidae) on _E. dodecella_ L.

C. deceptor is by far the most efficient of the above parasites. Figs. 3H and 3I show larvae of _E. nepheos_ parasitized by _C. deceptor_ (pupae). Table 2 shows the relative abundance of this parasite as compared to the others. The amount of parasitism appears to be increasing in Michigan. In 1969, 19.18% of the larval populations was parasitized (1152 infested buds examined) and by 1971 this increased to 37.63% (782 infested buds examined). In Ohio and Ontario, where the pine candle moth is of considerably less concern, degree of parasitism has been higher. Neiswander (1966) reports that approximately 43% of the larvae in two Ohio counties were parasitized and Martin (1959) found 50% of the larval population of _E. dodecella_ (pine bud moth) in two Ontario plantations parasitized. Degree of parasitism reaching these figures have only been obtained recently in Michigan indicating that an introduced _E. nepheos_ population was able to spread throughtout lower Michigan while the populations of biological control agents lagged behind.

Table 2. Relative rates of parasitism on Exoteleia nepheos during 1970*.

Parasite Family	Parasitized Larvae Number	Percent of Total
Encyrtidae (Copidosoma deceptor)	1083	79.50
Braconidae	152	11.38
Ichneumonidae	62	4.64
Eurytomidae	12	0.90
Eulophidae	9	0.67
Pteromalidae	8	0.60
Syrphidae	5	0.37
Eupelmidae	4	0.30

* Over 3000 infested Pinus sylvestris buds were collected at West Olive, Michigan.

Overwintering mortality may also be a strong limiting factor. In 3 population samples (ranging from 13 to 69 larvae) taken in January and March, from West Olive, Michigan (Appendix II), the percentage of dead larvae ranged from 46 to 100%. This may explain why the pine candle moth has not been reported in the northern part of the lower peninsula of Michigan; being unable to survive the harsh winters of these northern regions.

Adult Eclosion Period

The peak of adult eclosion is important for timing chemical control programs. Temperature (Appendix III) alone compared to adult trap collections was too variable - ranging between 54° and 80° F - to be useful. Instead, predicting peak of eclosion was attempted by the degree-day method. To do this it is necessary to determine the most reliable threshold temperature above which degree days are accumulated. This is typically done by plotting percent development over different temperatures and extrapolating to the point where the regression line crosses the abscissa, but Casagrande (1971) points out that this method is objectionable because it is hard to justify extending a regression line beyond data points. The method used instead is similar to that developed by Casagrande (1971). Degree days were determined for various threshold temperatures ranging from 42° to 76° F (Appendices IVa - IVf). Accumulated degree days were calculated from the daily maximum and minimum temperatures by using the sine curve method described by Baskerville and Emin (1969). Next, the degree days at which peak emergence occurs was recorded for all sites and the standard error determined (Appendix V). This was transformed into the coefficient of variability and plotted over threshold temperatures.

Development appears to start around the threshold temperature of 52°F (Fig. 7). Therefore by this method peak emergence can be expected to occur at about 1060±32(±S.E.) degree days above 52°F. threshold temperature. In practice, however, this gives only a rough estimate. The emergence pattern at East Lansing for 1969, 1970, 1971 (Fig. 8) shows a good prediction for 1969 but there was a delayed

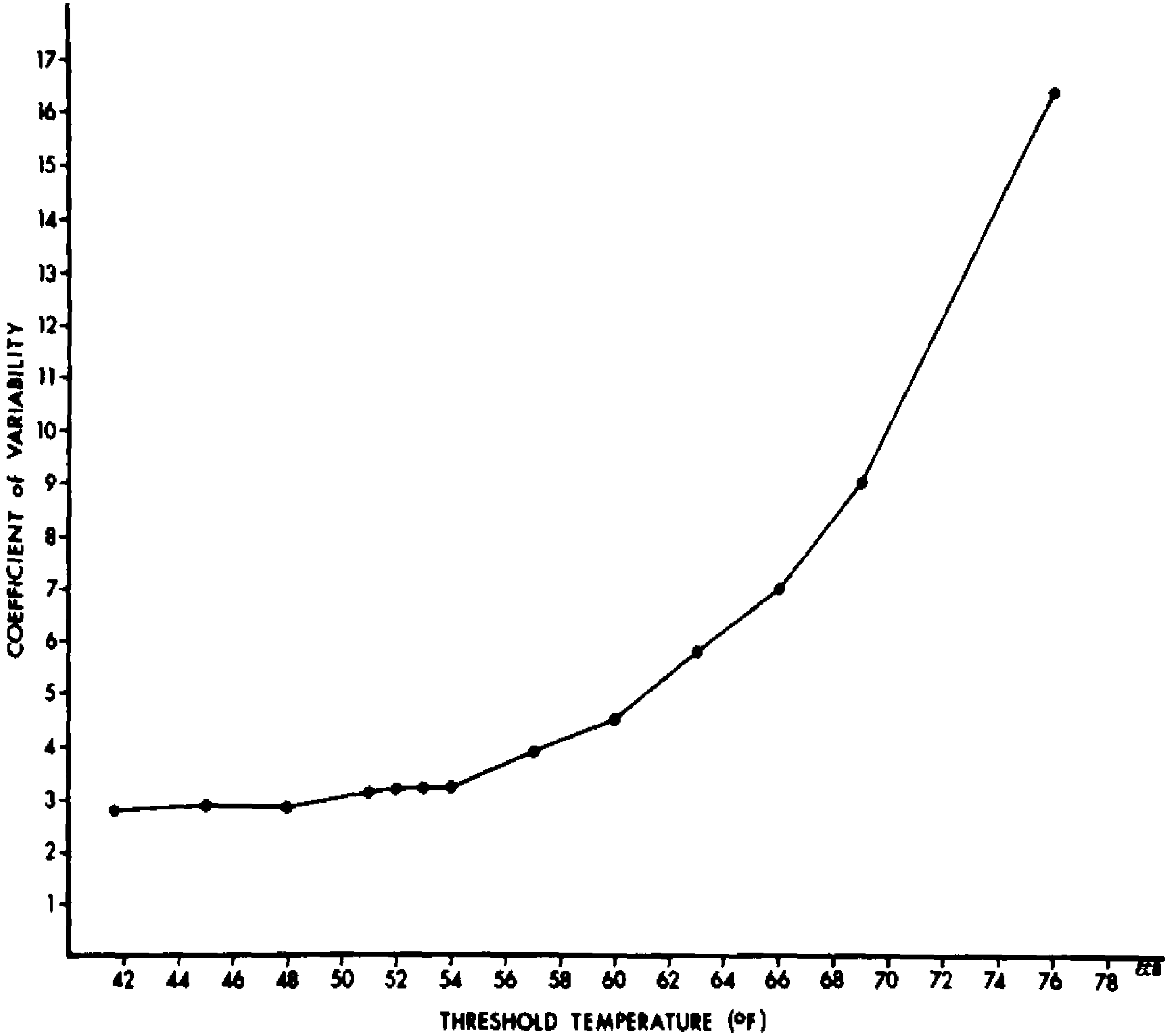

Fig. 7. Threshold temperature of larval development. Development appears to begin between 50 and 54°F.

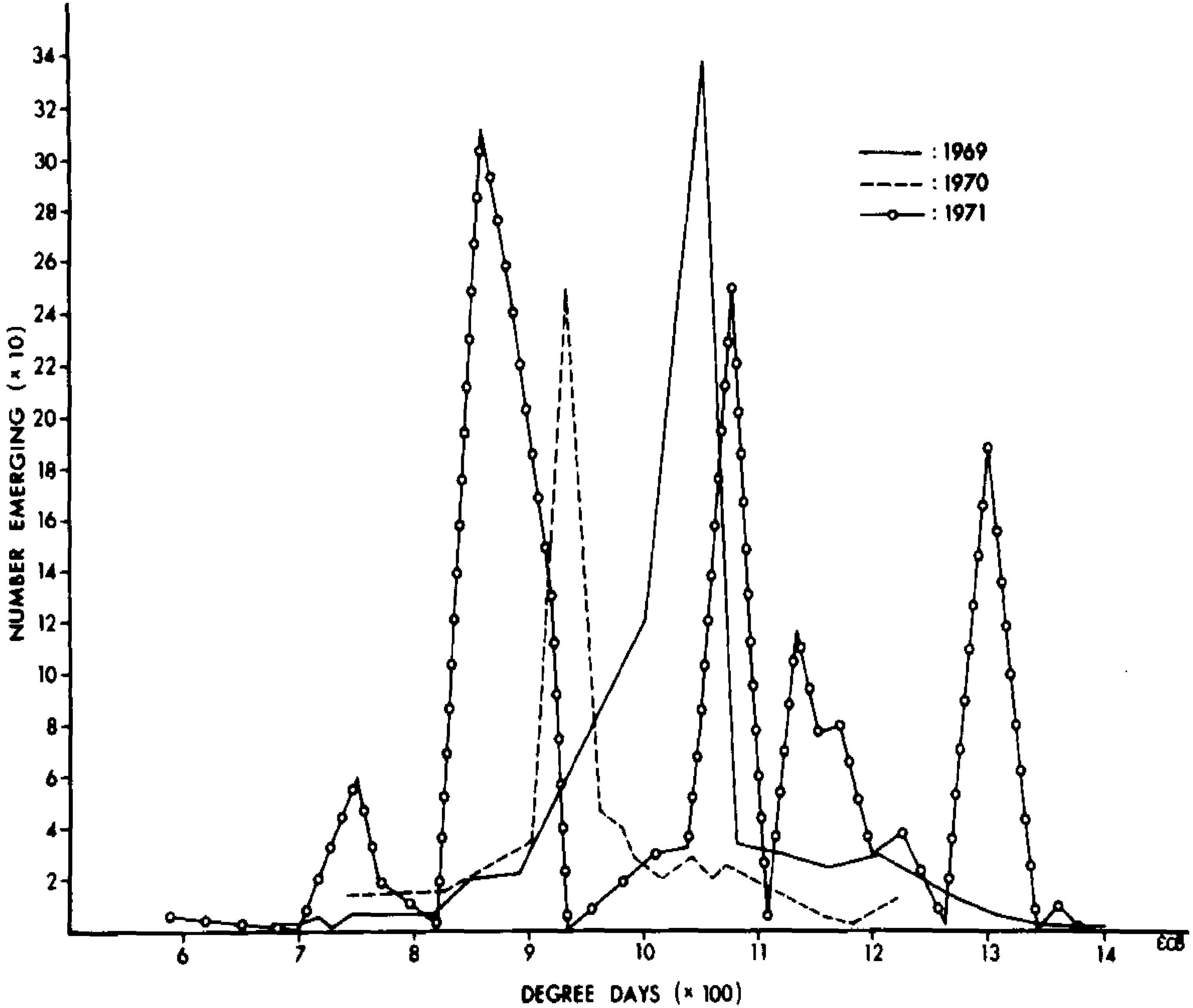

Fig. 8. Adult emergence of Exoteleia nepheos for 1969, 1970, 1971.

prediction for 1970 when 930 degree days would have given the peak. There were three unusually distinct peaks in 1971 which cannot be explained on the basis of degree days alone. If degree days was the only factor controlling emergence then one would expect a single peak curve as exhibited during the previous two years.

MANAGEMENT OF PINE CANDLE MOTH POPULATIONS

Research to develop integrated control necessitates a broad approach to insect pest problems. Consideration must be given to all potential methods of population reduction including biological, chemical and cultural controls, pheromones, attractants and plant resistance. This involves comprehensive information on the biology and ecology of the pest species on the host plant. Ultimately all of these techniques must be orchestrated to produce economical control without damage to the environment.

Materials and Methods

CHEMICAL CONTROL.-All chemical control experiments were done in infested plantations near West Olive, Michigan; trees ranged in height from 1.5 to 2 m. and had a basal diameter between 5 and 10 cm. The granular systemics included Temik®, Di-Syston®, Furadan®, Cygon®, and Dasanit®. During early May, prior to movement of the larvae from the needles to the buds, granules were applied to the soil around the periphery of the tree crown. The randomized block design had 5 replicated trees for each dosage rate of 22.8, 45.6, 91.2 and 114.0 grams of systemic per 1.0 cm. of tree diameter (2, 4, 8, and 10 oz/in. of dia.). Sufficient rain followed application to allow for soil penetration. Analysis of the treatments was done by collecting the infested buds and examining them for both pest and parasites.

In 1969 the following sprays were analyzed for control of E. nepheos larvae without regard to parasitism: 1) DDT - 1 gal of 25% emulsion/100 gal H_2O; 2) diazinon - 1 pt of 48% emulsion/100 gal H_2O; 3) Sevin® - 4 lbs of 50% wettable powder/100 gal H_2O; 4) methoxychlor - 1 gal of a 2 lb/gal emulsion/100 gal H_2O; 5) Cygon® - 3 pts of a 30.5% emulsion/100 gal H_2O; and 6) Guthion® - 1 qt of a 22% emulsion/100 gal H_2O. The randomized block design had 6 replications; each block consisted of 400 trees so that each treatment covered approximately 2400 trees. Application was done with a hydraulic sprayer (300 lbs of pressure) until run-off and it took 80-100 gals of insecticide to cover the 2400 trees. The program was initiated approximately 10 days after peak adult emergence, about the end of July, as determined by counts from a blacklight trap. Results were analyzed by randomly selecting a single tree from each block (6 trees for each treatment) and counting the number of dead buds and crooked candles.

In 1971 this experiment was repeated with a consideration of effects on parasitism as well. DDT and Cygon® were dropped from the experiment, and Meta-Systox-R® and Lannate® were added. The rates were as follows: 1) Meta-Systox-R® - 1.5 pts of a 25% emulsion/100 gal H_2O; 2) Guthion® - 2 qts of a 22% emulsion/100 gal H_2O; 3) diazinon same as in 1969; 4) Sevin® - 1.5 lbs of 80% wettable powder/100 gal H_2O; 5) Lannate® - 0.5 lbs of 90% wettable powder/100 gal H_2O. The sprays were applied by a hydraulic sprayer until runoff; approximately 8 gals of spray were used to cover 5 trees in a randomized block design. Application again was done approximately 10 days after peak emergence (end of July) to control the hatching larvae and measurements of the terminal growth of the 35 sprayed and control trees found the average to be approximately 14.00 ± 3.54 inches ($\pm$ S.D.) at this time. The experiment was analyzed by collecting infested buds and examining for healthy and parasitized larvae.

ATTRACTANTS.--Experimental attraction work was done in an infested Scotch pine plantation near Mayville, Michigan. Five to ten live adult moths, reared in an insectary at Michigan State University, were placed in an ice cream carton trap (Fig. 9A) and placed various distances from the infested stand to determine distance over which the attraction is effective. Sex of the adults placed within the traps was not determined until after the field experiment was complete.

A field screening test of 51 different chemical materials[4/] (Table 8) for attraction properties was also performed by placing 10 u liters of each test chemical into a polyethylene cap (Glass et al. 1970) (Scientific Products, 05-6 natural polyethylene closure for 60975-L, vials, 2-dram). The caps were placed in 3M® traps (Fig. 9B) and hung randomly on Scotch pine in the infested area (Roelofs and Comeau, 1970). They remained in the field through the month of July and trapped insects were periodically collected.

4/ Materials obtained from Martin Jacobson, Pesticide Chemicals Research Branch, Entomology Research Division, USDA, Beltsville, Maryland.

HOST RESISTANCE.-Two methods were attempted in investigating possible host resistance in the many varieties of Scotch pine: sleeve cage experiments on mature trees (Fig. 9C) and caged seedling experiments (Fig. 9D). Host material for the sleeve cage experiments came from a Scotch pine geographic origin study near East Lansing, Michigan (Wright, et al. 1966). Fifteen different varieties of 10 year old Scotch pine were tested with 4 replications, by caging one branch with a 20 x 20 mesh screen cage and releasing 10 adult moths into the cage. The following field season the results were analyzed by removing the caged branches and counting the number of mined needles and buds.

Red pine seedlings and eleven seed sources of Scotch pine, (2 years old) were obtained from Van's Pines in West Olive, Michigan and placed in six (12' x 19.5' x 6') cages. Each cage had 5 seedlings of each variety randomly dispersed and 70 adult moths were released in each. The results were analyzed the following field season by inspecting the needles and buds.

Chemical Control

Materials were tested not only for their ability to control the pine candle moth but also for their effect on the large number of parasites that attack E. nepheos. In one Michigan plantation 37.63% of 782 infested buds examined had larvae that were parasitized; most of this parasitism was by Copidosoma deceptor (Encyrtidae; Lepidoptera). Therefore, the ideal insecticide is one that reduces

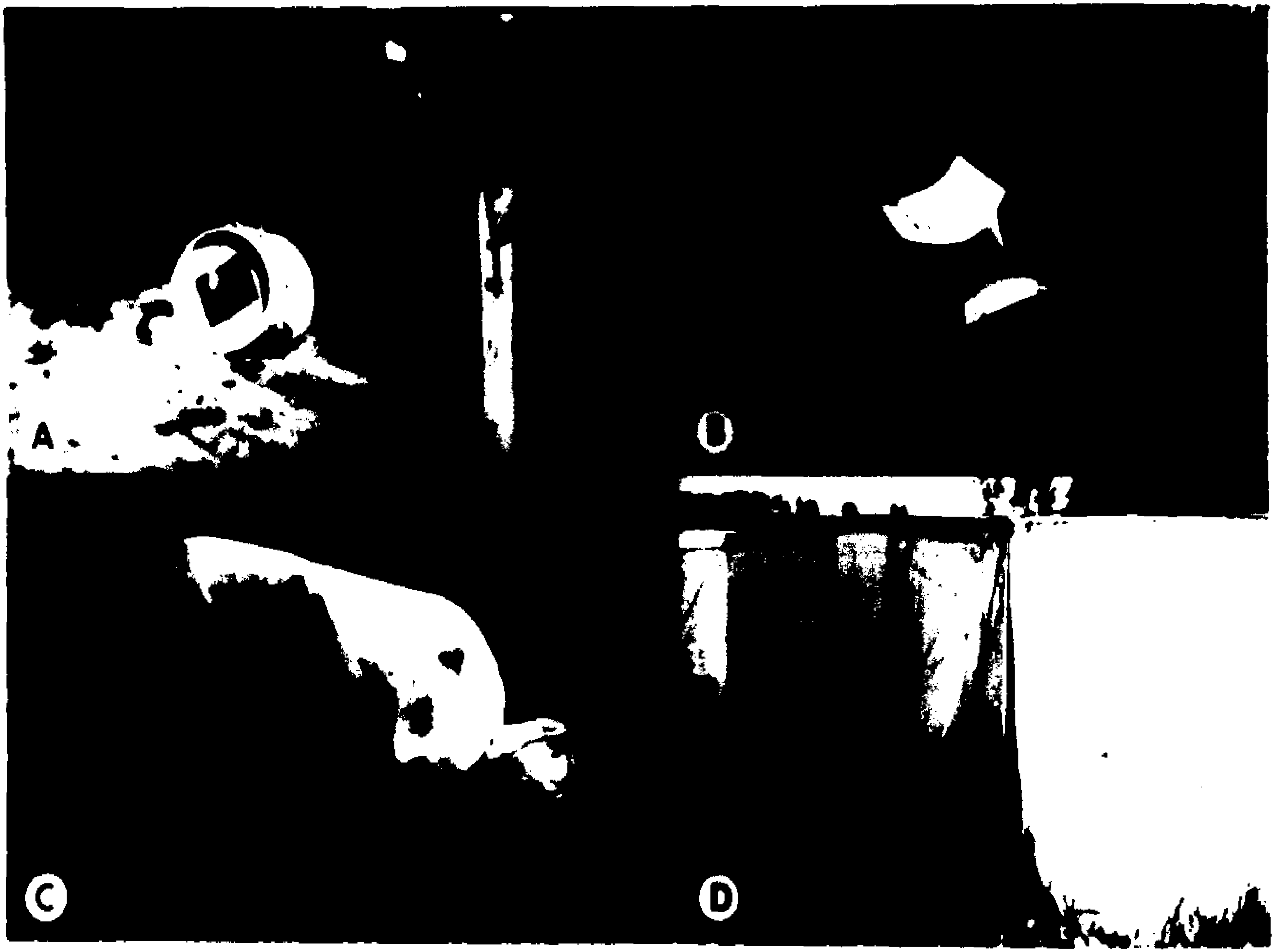

Fig. 9. A, pheromone trap baited with pine candle moths; B, pheromone trap baited with chemical materials; C, [illegible]x[illegible] mesh sleeve cage in which adults were released; D, 12'x19.5'x6' cage containing 6[illegible] seedlings and [illegible] pine candle moths.

the pine candle moth population to where the natural enemies of the pest can keep it below an economic threshold. In a preliminary experiment with the granular systemics it was desired to determine the proper rate of application. The granules were applied in a band between tree rows at a rate of 18.7 grams and 46.5 gram/m (0.2 and 0.5 oz/ft.). Rows between treatments were used as controls. None of the systemics showed any activity in controlling the larvae. There was no significant difference in the number of dead buds between treated and untreated rows.

The following year the rates of application were increased and the size of the trees was taken into consideration. The granules were applied to the soil around the periphery of the tree crown at 22.8, 45.6, 91.2 and 114.0 grams/cm of tree diameter. Both control and influence on parasites was investigated. Although in most cases the average percent mortality (Table 3) and the average rate of parasitism (Table 4) was higher than the controls, this was not statistically significant and it appears that these granular systemics are not active enough in Scotch pine, even at high dosages, to serve as adequate controls of the pine candle moth. No attempt was made to enhance the uptake of the insecticide into the tree by watering or raking the granules into the soil, but rain was frequent in the area.

Table 3. Influence of granular soil systemics on the pine candle moth.

Dosage Systemic/ Tree dia. grams/cm	Percent Mortality					
	Furadan®	Temik®	Di-Syston®	Dasanit®	Cygon®	Control
22.8	70.83	66.20	60.50	50.00	60.23	58.38
45.6	60.53	59.30	67.27	60.67	57.45	54.92
91.2	46.23	65.77	56.38	55.55	65.40	51.36
114.0	64.05	65.33	60.33	59.39	61.08	46.08

Table 4. Influence of granular soil systemics on the parasites of the pine candle moth.

Dosage Systemic/ Tree dia. grams/cm	Percent Mortality					
	Furadan®	Temik®	Di-Syston®	Dasanit®	Cygon®	Control
22.8	50.59	53.79	43.69	36.30	48.53	44.72
45.6	45.73	40.69	46.36	42.71	42.54	33.67
91.2	37.68	36.91	42.55	31.11	43.24	39.09
114.0	44.44	34.66	34.71	34.58	37.29	33.04

Of the foliar sprays tested Guthion®, diazinon and methoxychlor gave adequate control in 1969 (Table 5) while DDT and Cygon® showed no significant difference from the untreated controls. In 1971 Guthion®, diazinon and methoxychlor gave complete control (Table 6) while Sevin® and Meta-Systox-R® significantly reduced the number of infested buds. Lannate® was not significantly different from the untreated trees. Meta-Systox-R® and Sevin® had the least effect on the parasites of the pine candle moth

(Table 7) although these effects were not statistically significant according to Tukey's multiple comparison test.

Table 5. Control of the pine candle moth with chemical sprays - 1969

Treatment	Dead buds/tree	
	Average Number	Range
Guthion®	2.83c*	0-7
Diazinon	2.83c	0-8
Methoxychlor	2.92c	0-9
Sevin®	3.67bc	0-9
Cygon®	7.75abc	0-36
DDT	11.17ab	0-28
Control	11.67a	0-34

* Treatments which do not have the same letter are significantly different according to Tukey's multiple comparison test at the 5% level.

Table 6. Control of the pine candle moth with chemical sprays - 1971.

Treatment	Infested buds/tree	
	Average Number	Range
Guthion®	0 b*	0
Diazinon	0 b	0
Methoxychlor	0 b	0
Meta-Systox-R®	1.50 b	1-3
Sevin®	4.00 b	3-6
Lannate®	6.75 a	0-17
Control	16.30 a	9-29

* Treatments which do not have the same letter are significantly different accordingly to Tukey's multiple comparison test at the 5% level.

Table 7. Effect of chemical sprays on parasites of the pine candle moth.

Treatment	Parasitized Larvae	
	Percentage	Range
Guthion®	0	0
Diazinon	0	0
Methoxychlor	0	0
Lannate®	4.18	0-16.7
Sevin®	9.83	0-25.0
Meta-Systox-R®	20.83	0-50.0
Control	22.70	15.79-28.0

Attractants

During the 1970 field season a preliminary test was performed by placing 10 adult moths with Scotch pine foliage in each of 2 traps similar to those in Fig. 9A. Three other control traps were set; 2 with Scotch pine foliage and the other completely empty. All were sprayed with Tanglefoot® and placed around the edge of an infested plantation. Five days later they were examined and the baited traps had attracted 26 additional moths from the field population while the control traps had no captures. This was the first demonstration of an attraction associated with the pine candle moth.

During the next field season additional field tests were performed in Mayville and East Lansing. To demonstrate the power of the attraction, traps (Fig. 9A) were placed at various distances (1, 3, 7 and 10m) from an infested stand in Mayville. The results are shown in Fig. 10. A strong attraction occurred at the shorter distances and, from within 3m., was significantly higher than attraction at greater distances. Again the control traps had no captures.

The sex of the adults placed within the traps varied from predominately male to predominately female but only the latter produced an attraction. When traps were male or had a nearly even mixture of males and females, very few adults were captured. On the other hand, the sex ratio of the adults attracted to the traps

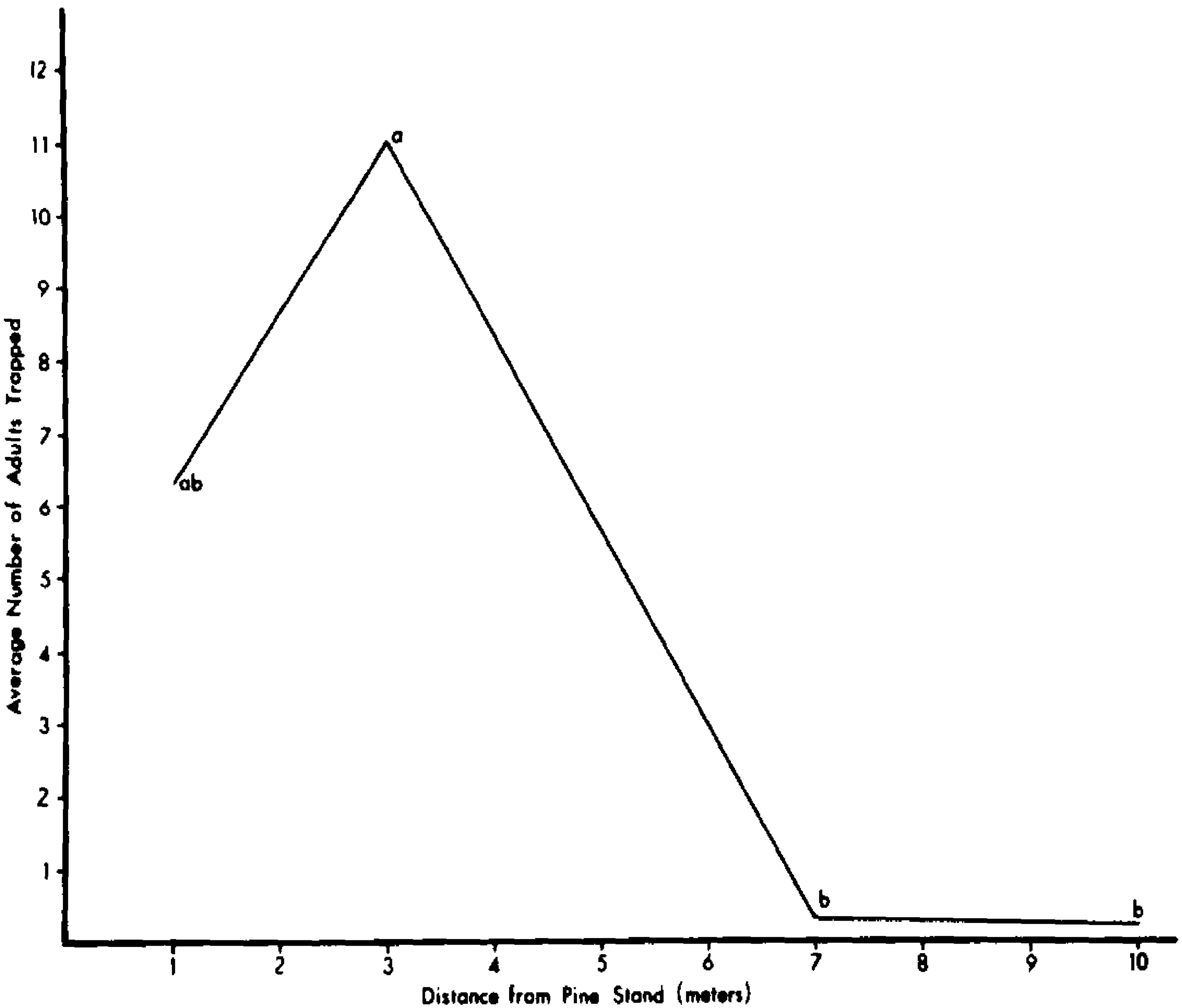

Fig. 10. Distance adult females, Exoteleia nepheos, could attract males from a Scotch pine stand. Distances which do not have the same letter are significantly different according to Tukey's multiple comparison test at the 5% level.

was approximately 9:1 in favor of males (this is only an approximation since the condition of many captured adults made sex determination difficult).

A release experiment was performed in an open field in East Lansing; 8 traps containing a preponderance of females, were staggered in 2 concentric circles of 1 and 2m radii and newly emerged adults were released from the center. No released adults were recaptured at the pheromone traps indicating the newly emerged moths were not immediately responsive to the attraction of females.

In a field (Mayville) screening test, 51 different chemicals were tested as possible pheromones of the pine candle moth (Fig. 9B). The materials are listed in Table 8 along with the number of adult E. nepheos captured. Results show no significant differences between chemicals and, evidently, the pheromone of the pine candle moth was not one of the materials, or, at least, was not present in a concentration competitive with the natural attraction. In an open field experiment (East Lansing) 9 materials (Ent. No. 1996, 17442, 34392, 3299, 21161, 21534, 24795, 522, and 33993; only these nine were used because of limited quantities of the material) were placed randomly in a semi-circle with a 2m radius and pine candle moths were released from the center (upwind). The results were also negative (no adults captured).

One interesting sidelight of the screening test done at Mayville

Table 8. Screening of Materials as Attractants for <u>Exoteleia</u> <u>nepheos</u>

Ent. No.*	Material	Adults Attracted Number
522	Terpineol, acetate	15
5859	Cyclohexanol, 2-phenyl-, acetate	19
941	Linalool, acetate	1
1025		7
1955	Ethanol, 2-ethoxy-, acetate	10
1996	Acetic acid, benzyl ester	10
11016	Furfuryl alcohol, acetate	2
11586	1-Tetradecanol, acetate	12
11595	1-Dodecanol, acetate	6
17442	Cyclohexaneethanol, acetate	16
17540	Fenchyl alcohol, acetate	6
18152	Benzyl alcohol, alpha-methyl-, acetate	6
18258	Cyclohexanol, 4-isopropyl-, acetate	10
18262	Cyclohexanol, 2-sec-butyl-, acetate	1
18336	Cyclohexanol, 2-cyclohexyl-, acetate	2
207	Geraniol, acetate	8
21161	Benzyl alcohol, p-ethoxy-, acetate	9
21209	Furfuryl alcohol, tetrahydro-, acetate	3
21282	Benzyl alcohol, 3, 4-dimethyl-, acetate	8
21527	Benzyl alcohol, p-ethyl-, acetate	3
21537	Benzyl alcohol, O-methyl-, acetate	4
21902	Benzyl alcohol, m,ethyl-, acetate	3
21534	Benzyl alcohol, 2, 5-dimethyl-, acetate	18
24138	Acetic acid, undecyl ester	6
24795	2-Butanol, 3-methyl-4-phenyl-, acetate	16
3294	Acetic acid, cyclohexyl ester	13
33824	trans-5-hexadecen-1-ol, acetate	8
3429	Carvacrol, acetate	12
3878	Acetic acid, phenethyl ester	9
30099	3-Cyclohexene-1-methanol, alpha, alpha-6-trimethyl-, acetate	6
30725	Acetic acid, esooctyl ester	8
31164	1, 3-Dioxolane-4-methanol, 2-phenyl-, acetate	3
31166	1, 3-Dioxolane-4-methanol, 2-(6-methyl-3-cyclohexen-1-yl), acetate	5
31183	1, 3-Dioxolane-4-methanol, 2-benzyl-, acetate	8
31186	1, 3-Dioxolane-4-methanol, 2-p-tolyl-, acetate	4
31227	1, 3-Dioxolane-4-methanol, 2-ethyl-2-methyl-, acetate	0
31833	2-Butanone, 4-(p-hydroxyphenyl)-, acetate	7
33265	7-Dodecyn-1-ol, acetate	3
32266-b	cis-7-Dodecen-1-ol, acetate	1
33478-h	cis-7-Hexadecen-1-ol, acetate	3
33538	10-Isopropyl-11-methyl-cis-5, 9-Dodecadien-1-ol, acetate	11
33845	10-Isopropyl-cis-5, 9-Tridecadien-1-ol, acetate	3
33971	cis-9-Dodecen-1-ol, acetate	4
33993	cis-8-Dodecen-1-ol, acetate	11
33994	trans-8-Dodecen-1-ol, acetate	5
34180	cis-4-Hexadecen-1-ol, acetate	8

Table 8 Continued

34370	8-Nonen-1-ol, acetate	5
34392	cis-3-hexen-1-ol, acetate	14
34395	2-Nonen-1-ol, acetate	8
34412	2, 4-Undecadien-1-ol, acetate	8
34462	7-Butoxy-1-heptanol, acetate	9

* Ent. No. appear in "Materials tested as insect attractants", Agriculture Handbook No. 239, Agr. Res. Ser. USDA.

was that 160 individuals of Elatobia martinella[5/] Walker (Tineinae) were captured in the 3 traps containing cis-9-Dodecen-1-01 acetate. This attraction was very strong as these moths were observed fluttering around the field lab as the materials were being placed in the traps. As far as can be determined this is the first record of this insect appearing in Michigan. According to Forbes (1923) the larvae bore in the bark of Pinus spp. during early spring and the adults appear in June. But, apparently they are of no economic importance.

[5/] Identified by J. H. Newman, Michigan State University.

Host Resistance

The sleeve cage experiments on mature trees gave highly variable results (Table 9) that showed no significant differences between varieties at the .05 level of significance. The experiment in which adult pine candle moths were released in cages containing various varieties of Scotch pine was not successful. No evidence of oviposition or insect damage was found. Under these highly artificial conditions any number of factors could have influenced the ability of the adults to mate and oviposite and the results do not necessarily indicate that there is no host resistance.

Table 9. Susceptibility of 15 varieties of *Pinus sylvestris* to attack by *Exoteleia nepheos* when caged on individual branches.

Variety	Seed Source	Average Dead Needles	Number Dead Buds
altaica	Southern Siberia	21.50±33.75*	0.50±1.00
sepentrionalis	South-central Sweden and Norway, Southern Finland	20.25±23.47	3.00±4.08
rigensis	Latvian SSR, S. Sweden	19.50±24.24	1.50±1.91
uralensis	Ural Mountains	25.75±30.73	2.00±2.83
polonica	Poland	20.75±27.89	2.00±2.83
borussica	Lowlands of Northeastern Germany	50.33±42.83	0.67±0.58
hercynica	Germany, Czechoslovakia	25.60±37.29	2.00±4.47
haguenensis	Belgium, Vosges Mountains of France, adjacent Germany	65.25±95.82	2.00±2.45
'*East Anglia*'	England	36.25±70.51	0.75±1.50
'*N. Italy*'	Northern Italy	34.50±35.91	0.75±0.96
illyrica	Yugoslavia	40.00±65.00	0.33±0.58
iberica	Spain	30.50±38.90	3.00±6.00
aquitana	Central Massif of France	24.00±28.14	0.00
rhodopaea	Greece	34.75±43.89	3.00±1.58
armenea	Turkey, Caucasus Mtns.	32.75±25.24	2.00±2.71

* Standard deviation.

DISCUSSION

CHEMICAL CONTROL.-The biology of the pine candle moth is such that the possibility of developing an efficient integrated control program that takes advantage of the high rate of natural parasitism appears extremely promising. Although Guthion®, diazinon and methoxychlor gave excellent control of the pine candle moth, the evidence indicates that Meta-Systox-R® may be a more effective material in a control program. In the present study Meta-Systox-R® significantly reduced the number of infested buds while not completely eliminating them; thus leaving breeding material for the numerous parasites that attack *E. nepheos* and allowing them to keep the pine candle moth population under an economic threshold and possibly avoiding the necessity of future spray programs. In a preliminary experiment in Ohio, Campbell (1968) found that Meta-Systox-R® apparently reduced the pine candle moth population by about 50% while having little effect on the parasites. In an integrated control experiment on Scotch pine (Campbell and Balderston, 1971) to control the pine candle moth, the European pine sawfly, *Neodiprion sertifer* (Geoffroy, and the spotted pine aphid, *Eulachnus agilis* (Kaltenbach) Meta-Systox-R® was applied in early May while the larvae of the pine candle moth were boring in the buds. This did not reduce the number of larvae infesting the candles but did reduce the number of needle mining larvae of the ensuing generation. Furthermore, parasitism of the larvae was not lessened by this treatment.

ATTRACTANTS.-The pheromone tests indicate that the chemical, once identified, could be used as a survey tool to determine infestations within a stand; thus avoiding unnecessary spraying of uninfested or lightly infested stands. The negative results of the release experiments indicates that some preconditioning of the pine candle moth may be necessary before the adult male is receptive to the pheromone. Daterman (1972) found that the incidence of male sexual response of *Rhyacionia buoliana* (Schiffermuler) depended upon the length of time males were conditioned at high illumination.

HOST RESISTANCE.-The host resistance studies were inconclusive. It appears that only under natural conditions could host resistance to the pine candle moth be verified. For example, Wright, et al. (1966 and 1967) observed four plantations that had 108 seedlots each of *Pinus sylvestris* L. infested with the European pine sawfly, *Neodiprion sertifer*. They found that the percentage of trees attacked varied from 0 to 6 for north Eurasian varieties, 6 to 11 for south European varieties, and 12 to 26 for central European varieties. Something similar may occur with the pine candle moth.

Bennett (1954) reported a host resistance factor with the pine needle miner, *Exoteleia pinifoliella* (Chamb.), attacking various species of host trees. He found a correlation between the internal structure of a pine needle and its susceptibility to injury. Of the many species this pest attacks, lodgepole pine and jack pine were the most favored. The needles of these 2 species have only 2 moderate-sized resin canals located in each corner of the needle. Scotch pine, on the other hand, was definitely undesirable as a host tree with conspicuous resin canals varying from 6 to 16; the higher the number, the greater the resistance to the insect apparently due to the copious resin flow.

CONCLUSIONS AND RECOMMENDATIONS

Although an estimate of peak adult emergence of the pine candle moth was made at 1060±32 degree days above 52°F. threshold temperature, the variability involved in this estimate appears too great to be reliable from year to year. Therefore, black light traps or possibly pheromone traps should be employed to determine peak eclosion. An exact measure is important for determining the best time for control operations. Pesticide applications ten days after peak adult emergence, or at the time of egg hatch, gives good control. At any other time in the life cycle, the pest is well protected within the needle or candle mines and controls would be less effective.

Choice of insecticide is very important. Since there are a large number of parasites which attack this species and since they appear to be of some importance in keeping the population levels of E. nepheos down, consideration should be given to the effect of the pesticide on the parasite populations. In the present study Guthion®, diazinon and methoxychlor all gave excellent control. However, these materials also appeared to have an adverse effect on the parasites. Meta-Systox-R®, on the other hand, gave less control but also appeared to have less effect on the parasites. Possibly this material can bring the pest population down to acceptable levels where it can be maintained by the parasite population.

Future research should attempt to verify these statements by a long-term study on the effects of these materials on both the pest and parasite populations. This would involve an intensive population dynamics study that would closely examine the relationship of parasite to pest, including when the parasites are present, which species are most important, and what densities would result in a significant reduction in the pest population. Furthermore, mortality due to overwintering appears to be an important part of the life history of the pine candle moth and should be examined more closely.

Other tools that may be useful in a control program include attractants and host resistance. This study has demonstrated that a sex pheromone does exist, but further research is needed to determine the exact chemical. The attractant we used is not very powerful in attracting adult males over short distances. Perhaps the pheromone would have been stronger when in association with host volatiles. If a strong attractant can be identified and synthesized, it may prove of immense value in surveying for infested areas. If the pine candle moth should become an even more serious pest and become a threat to areas not now infested, surveying with pheromone traps could pin-point these areas rapidly so that prompt control measures can be taken. Furthermore, these surveys would prevent the needless spraying of pesticides in uninfested areas.

Although host resistance was not demonstrated in this research, resistance has been demonstrated within varieties of Scotch pine for other pest species and may also exist for the pine candle moth. Perhaps this could be demonstrated under natural conditions where the insect has a choice between varieties.

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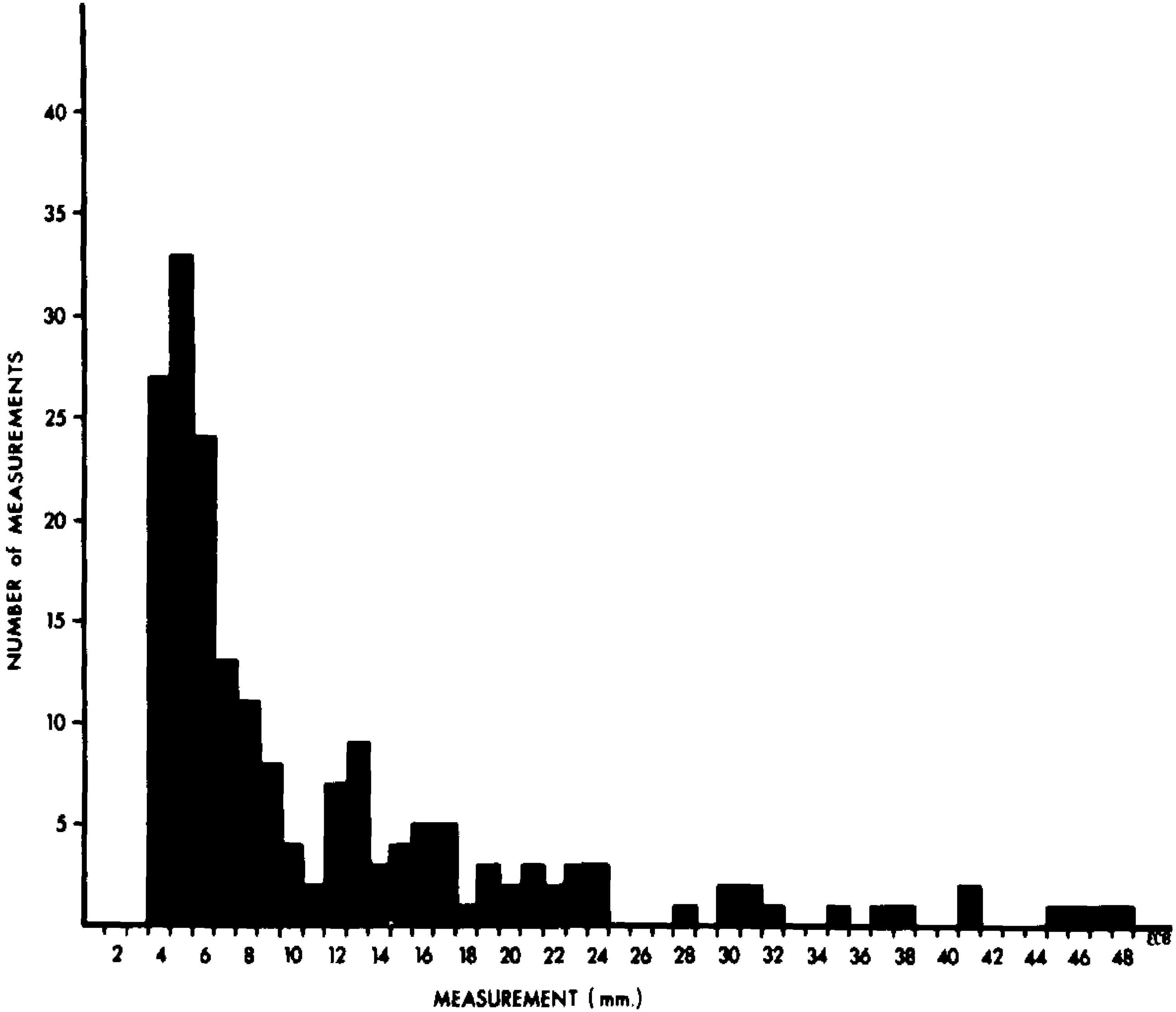
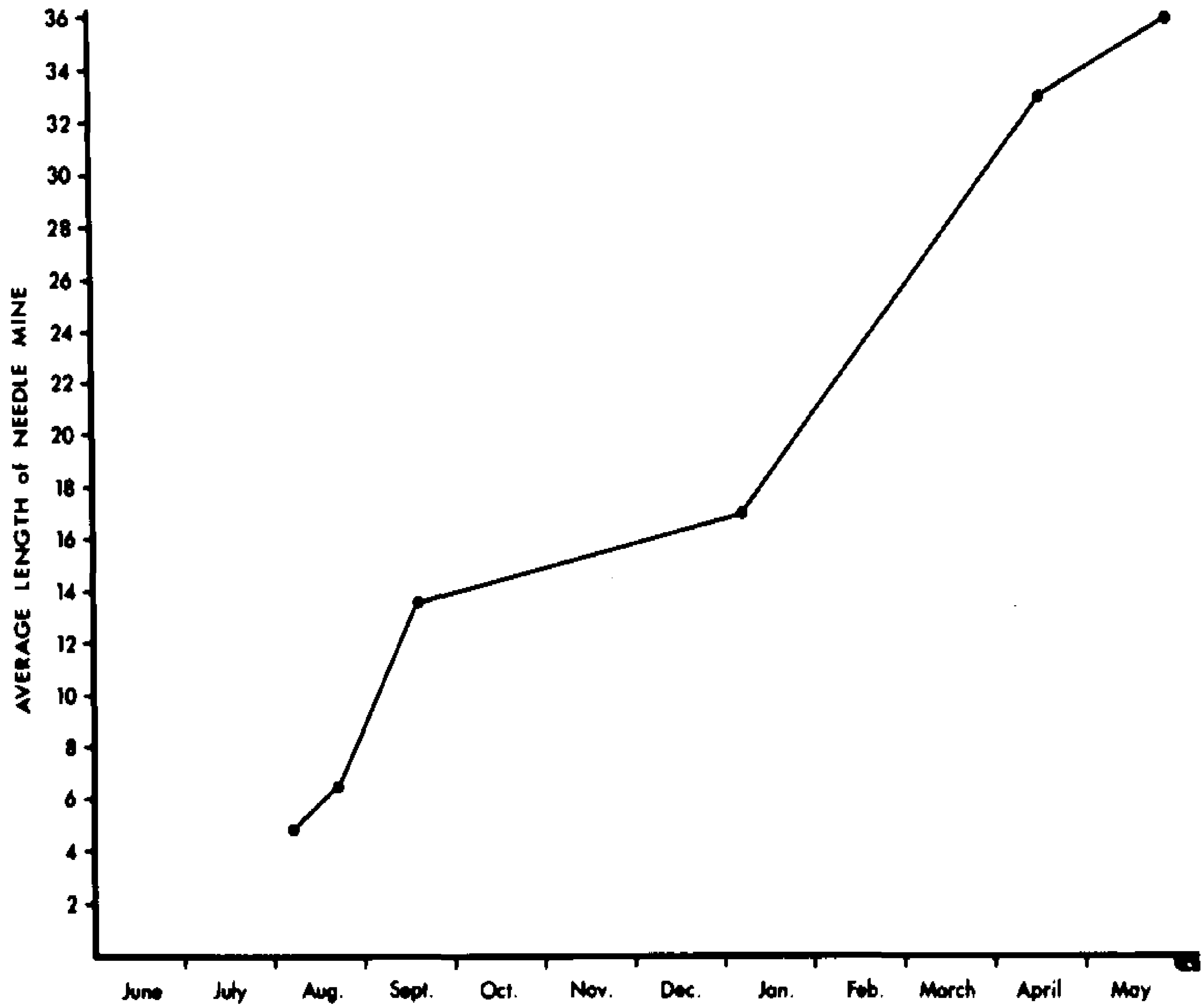
APPENDICES



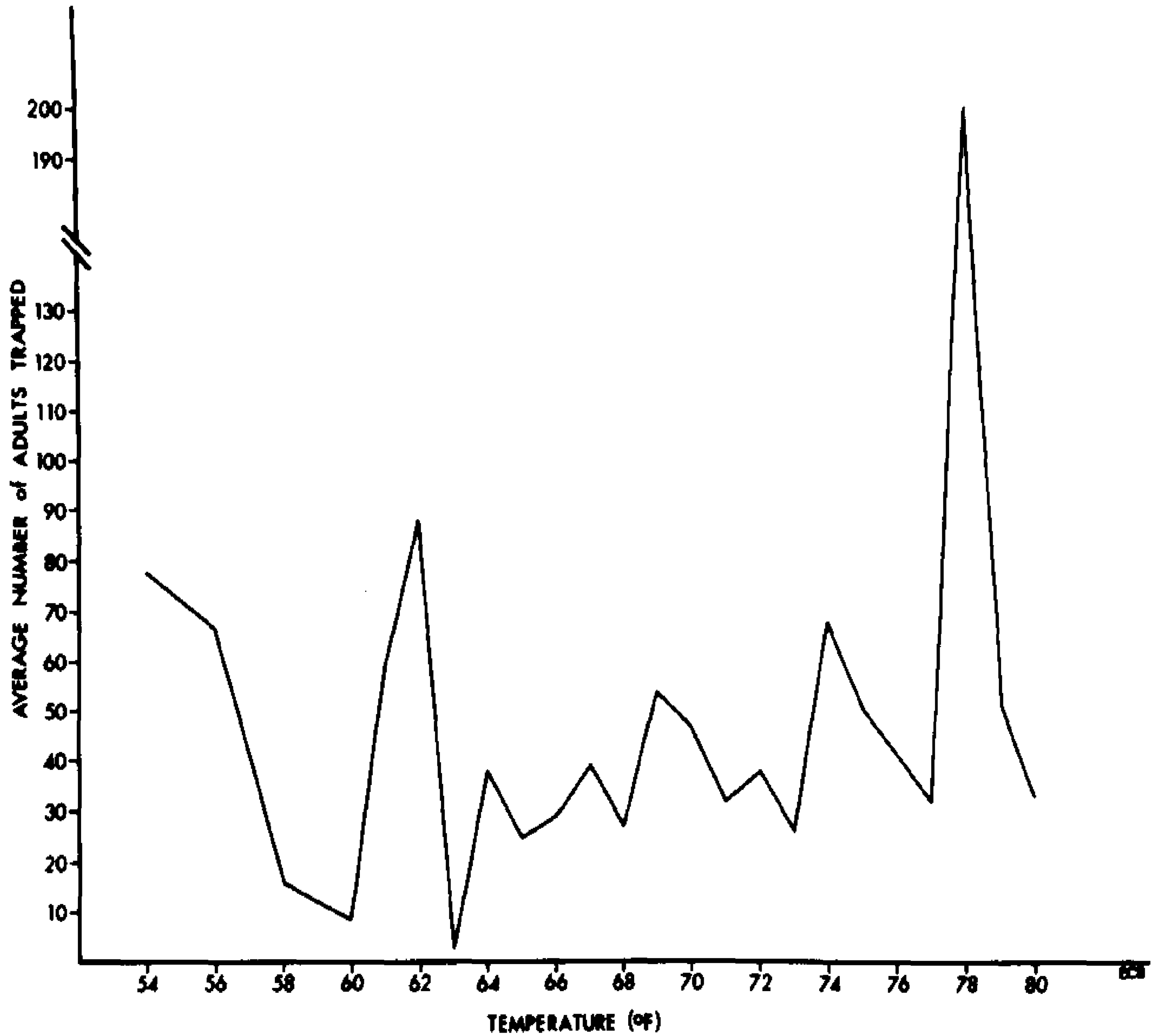
Appendix Ia. Lengths of 191 needle mines excavated by larvae of the pine candle moth.



Appendix Ib. Average seasonal length of needle mines excavated by larvae of the pine candle moth.

Appendix II. Larval mortality during various sampling dates.

Date	Sample Size Number	Larval Mortality Percentage
1/9/70	69	82.61
3/30/70	15	100.00
3/30/71	13	46.15
4/17/70	29	44.83
5/29/70	8	0.00
5/6/71	19	26.32
6/15/71	7	28.57
8/5/69	21	42.86
8/20/69	58	18.96
8/28/70	36	8.33
9/18/69	29	44.83



Appendix III. Mean temperatures and adult emergence of the pine candle moth during 1971 at East Lansing, Michigan.

Appendix IVa. Accumulation of degree days from January 1 to August 31, 1969 at West Olive, Michigan.

Threshold 52° F.

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0	0	0	18	128	385	713	1300
2	0	0	0	18	139	387	723	1314
3	0	0	0	18	149	387	741	1328
4	0	0	0	18	160	391	763	1342
5	0	0	0	20	178	396	789	1358
6	0	0	0	20	194	401	803	1378
7	0	0	0	22	208	410	818	1400
8	0	0	0	31	214	415	832	1420
9	0	0	0	41	215	420	850	1438
10	0	0	0	46	215	427	870	1450
11	0	0	0	46	215	443	892	1462
12	0	0	0	48	215	469	913	1478
13	0	0	0	53	219	479	931	1498
14	0	0	0	60	226	486	952	1520
15	0	0	0	69	236	492	976	1546
16	0	0	0	73	252	499	1001	1570
17	0	0	1	81	270	511	1025	1594
18	0	0	5	88	272	520	1045	1618
19	0	0	9	89	273	532	1063	1641
20	0	0	11	91	274	539	1084	1653
21	0	0	11	94	274	544	1102	1664
22	0	0	11	94	275	551	1122	1675
23	0	0	13	94	277	558	1144	1688
24	0	0	18	95	282	566	1164	1709
25	0	0	18	98	288	586	1183	1727
26	0	0	18	107	294	613	1203	1747
27	0	0	18	121	308	643	1221	1764
28	0	0	18	123	328	663	1238	1786
29	0	0	18	123	349	680	1252	1810
30	0	0	18	123	358	702	1266	1835
31	0	0	18	123	373	702	1286	1859

Appendix IVb. Accumulation of degree days from January 1 to August 31, 1970 at West Olive, Michigan.

Threshold 52^{o} F.

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0	0	0	0	118	446	929	1511
2	0	0	0	0	118	458	955	1527
3	0	0	0	0	122	464	977	1547
4	0	0	0	0	127	471	992	1554
5	0	0	0	0	130	482	1002	1564
6	0	0	0	0	130	491	1013	1577
7	0	0	0	0	136	505	1031	1593
8	0	0	0	4	152	523	1050	1612
9	0	0	0	6	172	542	1064	1630
10	0	0	0	6	186	563	1077	1650
11	0	0	0	6	197	587	1095	1670
12	0	0	0	7	207	612	1111	1687
13	0	0	0	7	215	629	1135	1705
14	0	0	0	10	222	649	1161	1725
15	0	0	0	13	228	667	1185	1749
16	0	0	0	16	229	689	1202	1773
17	0	0	0	19	230	716	1223	1787
18	0	0	0	19	239	736	1242	1798
19	0	0	0	19	255	746	1258	1821
20	0	0	0	19	271	754	1268	1838
21	0	0	0	19	291	762	1276	1849
22	0	0	0	22	309	771	1288	1861
23	0	0	0	27	323	788	1299	1873
24	0	0	0	29	337	806	1316	1883
25	0	0	0	37	351	815	1338	1899
26	0	0	0	44	357	827	1362	1917
27	0	0	0	57	359	836	1388	1935
28	0	0	0	69	372	848	1414	1959
29	0	0	0	89	388	874	1439	1971
30	0	0	0	108	408	901	1463	1989
31	0	0	0	108	428	901	1487	2001

Appendix IVc. Accumulation of degree days from January 1 to August 31, 1971 at West Olive, Michigan.

Threshold 52^{o} F.								
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0	0	0	15	83	283	821	1258
2	0	0	0	15	84	294	835	1272
3	0	0	0	15	84	303	850	1280
4	0	0	0	15	84	320	868	1292
5	0	0	0	15	87	340	888	1303
6	0	0	0	15	94	359	906	1314
7	0	0	0	15	100	381	924	1325
8	0	0	0	20	105	392	944	1337
9	0	0	0	26	109	400	964	1357
10	0	0	0	27	116	410	980	1383
11	0	0	0	35	122	424	998	1393
12	0	0	0	47	126	443	1013	1403
13	0	0	0	48	129	462	1035	1422
14	0	0	5	48	136	475	1047	1444
15	0	0	7	49	148	493	1057	1462
16	0	0	7	54	159	508	1073	1474
17	0	0	7	58	171	525	1086	1486
18	0	0	7	61	193	546	1097	1499
19	0	0	7	68	209	565	1106	1519
20	0	0	7	75	213	593	1115	1540
21	0	0	7	79	217	609	1128	1562
22	0	0	7	79	222	622	1146	1580
23	0	0	7	80	230	639	1162	1592
24	0	0	7	80	242	657	1180	1602
25	0	0	7	81	245	679	1196	1618
26	0	0	7	81	245	698	1210	1630
27	0	0	7	81	247	722	1218	1642
28	0	0	7	81	252	751	1226	1652
29	0	0	7	81	258	778	1233	1663
30	0	0	7	82	266	803	1239	1681
31	0	0	11	82	277	803	1246	1695

Appendix IVd. Accumulation of degree days from January 1 to August 31, 1969 at East Lansing, Michigan.

Threshold 52° F.

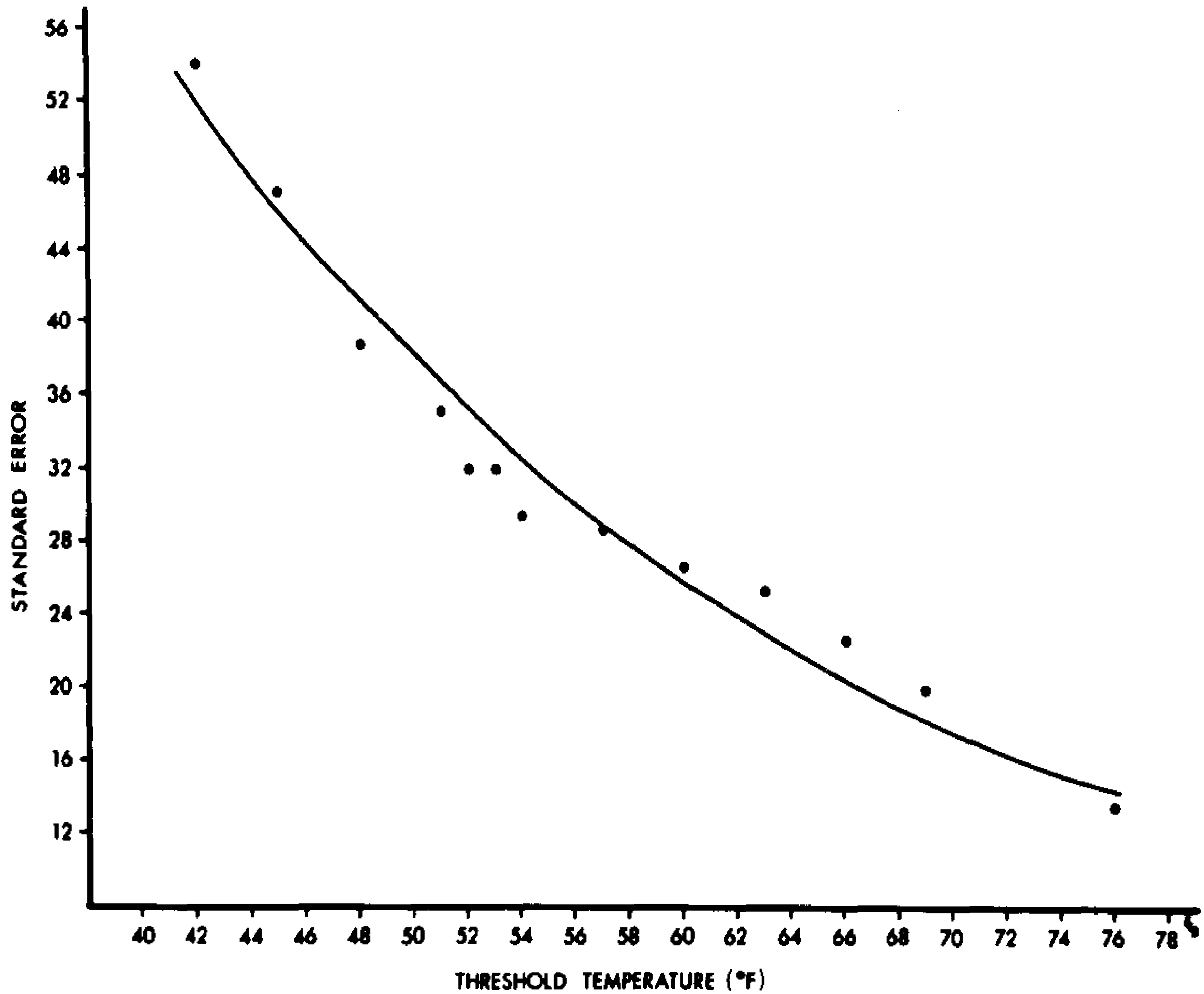
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0	0	0	21	123	388	732	1323
2	0	0	0	21	134	391	744	1339
3	0	0	0	21	150	391	760	1355
4	0	0	0	21	160	397	778	1372
5	0	0	0	23	170	400	800	1390
6	0	0	0	23	184	405	816	1410
7	0	0	0	27	202	414	827	1430
8	0	0	0	35	218	415	839	1447
9	0	0	0	40	219	422	854	1464
10	0	0	0	43	219	431	878	1478
11	0	0	0	43	219	447	900	1492
12	0	0	0	44	219	475	920	1508
13	0	0	0	48	224	493	940	1528
14	0	0	0	55	230	505	961	1550
15	0	0	0	61	237	512	983	1577
16	0	0	0	71	250	520	1009	1602
17	0	0	2	79	264	532	1037	1626
18	0	0	7	79	264	542	1057	1650
19	0	0	11	79	266	558	1068	1674
20	0	0	13	81	271	567	1087	1684
21	0	0	13	81	275	572	1107	1696
22	0	0	13	81	275	580	1125	1708
23	0	0	17	81	278	586	1145	1731
24	0	0	21	83	284	596	1166	1753
25	0	0	21	87	291	610	1185	1778
26	0	0	21	97	296	636	1206	1798
27	0	0	21	110	307	666	1228	1814
28	0	0	21	119	321	689	1247	1835
29	0	0	21	119	344	703	1267	1857
30	0	0	21	120	360	719	1284	1883
31	0	0	21	120	374	719	1304	1909

Appendix IVe. Accumulation of degree days from January 1 to August 31, 1971 at East Lansing, Michigan.

Threshold 52° F.								
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0	0	0	11	97	332	917	1441
2	0	0	0	11	97	347	931	1459
3	0	0	0	11	98	361	948	1469
4	0	0	0	11	100	380	968	1481
5	0	0	0	11	106	400	986	1493
6	0	0	0	11	111	424	1007	1507
7	0	0	0	12	116	448	1027	1525
8	0	0	0	17	124	463	1049	1544
9	0	0	0	23	132	471	1071	1565
10	0	0	0	24	141	480	1091	1593
11	0	0	0	30	151	495	1111	1613
12	0	0	0	42	155	517	1125	1627
13	0	0	0	51	159	589	1152	1647
14	0	0	3	51	165	557	1168	1669
15	0	0	5	53	176	573	1182	1685
16	0	0	5	59	190	590	1200	1698
17	0	0	5	66	202	610	1217	1713
18	0	0	5	70	223	630	1230	1731
19	0	0	5	75	243	654	1246	1751
20	0	0	5	83	247	678	1358	1775
21	0	0	5	91	251	698	1272	1801
22	0	0	5	92	255	715	1295	1822
23	0	0	5	94	262	733	1317	1838
24	0	0	5	95	276	753	1337	1848
25	0	0	5	95	287	777	1357	1868
26	0	0	5	95	287	797	1375	1886
27	0	0	5	95	291	825	1385	1900
28	0	0	5	95	296	854	1396	1915
29	0	0	5	95	304	884	1406	1929
30	0	0	5	96	315	901	1419	1948
31	0	0	7	96	326	901	1428	1962

Appendix IVf. Accumulation of degree days from January 1 to August 31, 1971 at Mayville, Michigan.

Threshold 52° F.								
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	0	0	0	3	73	313	904	1436
2	0	0	0	3	74	324	920	1452
3	0	0	0	3	74	338	932	1464
4	0	0	0	3	77	355	949	1474
5	0	0	0	3	83	374	973	1485
6	0	0	0	3	89	396	995	1498
7	0	0	0	3	93	417	1010	1515
8	0	0	0	5	99	432	1038	1535
9	0	0	0	9	107	437	1060	1557
10	0	0	0	9	116	445	1077	1587
11	0	0	0	16	126	460	1097	1603
12	0	0	0	28	130	483	1110	1615
13	0	0	0	36	136	509	1134	1637
14	0	0	0	36	141	527	1152	1661
15	0	0	2	37	154	542	1164	1675
16	0	0	2	40	171	558	1182	1687
17	0	0	2	43	181	580	1199	1703
18	0	0	2	45	203	600	1210	1720
19	0	0	2	50	225	625	1225	1738
20	0	0	2	57	230	653	1237	1764
21	0	0	2	64	235	677	1252	1788
22	0	0	2	65	239	691	1278	1808
23	0	0	2	68	245	707	1304	1826
24	0	0	2	70	259	723	1324	1834
25	0	0	2	70	271	741	1341	1854
26	0	0	2	70	271	755	1365	1870
27	0	0	2	70	274	784	1374	1882
28	0	0	2	70	279	814	1384	1897
29	0	0	2	70	287	846	1395	1912
30	0	0	2	71	298	876	1409	1926
31	0	0	2	71	310	876	1422	1938



Appendix V. Standard errors of degree days at peak adult emergence and various threshold temperatures.