PROCEEDINGS OF THE EIGHTH ANNUAL NORTHEASTERN FOREST INSECT WORK CONFERENCE

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Techniques for Research, Development, and Application

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AN OVERVIEW OF THE EIGHTH ANNUAL NORTHEASTERN FOREST INSECT WORK CONFERENCE

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RD&A is the abbreviation for the three basic components of a pest-management program: Research, Development, and Application. Unfortunately, the shortcut is used so loosely we often forget the magnitude and importance of the relationship between the three, and that it takes a super management, communication, and cooperation effort to meld them into a problem-solving unit. The theme for this year's Work Conference, "Techniques for Research, Development and Application," was a direct response to the need for more communication. The objective was to provide a forum where current and proposed techniques could be reviewed, evaluated, and discussed and where cooperation could be fostered.

The workshop topics were chosen from responses to a questionnaire sent to 150 participants in previous Northeastern Forest Insect Work Conferences. The survey indicated an overwhelming interest in all aspects of parasite use in a pest-management program. For this reason, two parasite workshops were scheduled: (1) "Parasite Evaluation," and (2) "Parasite Management." "Evaluation," as it is presently used in conjunction with parasites, has several ingredients; some are qualitative, such as the determination of certain physiological responses to varying environments (diapause, etc.), while others are quantitative, such as the development of sampling schemes for measuring percentage of parasitism. Parasite management emphasizes the effective utilization of parasites in a pest-management program, by inoculative releases, by inundative releases, by enhancement of established parasite populations, or by combinations of the above.

One would suppose that evaluation must precede management if, indeed, management is to exist. But this is more the exception than the rule. The parasite workshops were designed to increase our understanding of the relationship between evaluation and management and to bridge the communication gap that seems to exist between research (evaluation) and application (management).

Techniques for sampling one or more of an insect's life stages was on everyone's list. Importance of sampling in all aspects of research, development, and application was reflected in the excellent participation at the sampling workshop; one got the impression that without sampling a pest-management program was just so much wishful thinking.

Behavioral chemicals have received their share of program time in most insect workshops and symposia in the last 5 years and this Conference was no exception. Very simply, there is a lot of important and interesting work being done, and apparently, people want to know about it. The use of behavioral mediating chemicals (BMC) is relatively new to pest management programs; yet, like many new things, we've tagged them with a super-solution label and dragged them into the development-and-application phase of pest-management programs without completing the research. As with previous so-called "super solutions," BMC has been returned to the laboratory for more intensive investigation. The potential is still there — that's what generates the interest.

The topic "Identification of Insect Pathogens" placed high in the techniques-we-want-to-know-more-about category. Although insect pathogens are primary organisms that affect the dynamics of most insect populations, the expertise required to identify them often precluded their identification so that insect mortality has simply been listed as "diseased." Now, however, several factors, relatively new to forest insect programs, necessitate more precise evaluation of diseased specimens. These are: (1) the use of pathogens as bacteriocides; (2) the necessity of controlling disease in laboratory insect colonies, particularly in mass-rearing programs; and (3) an increased emphasis to identify the factors that regulate insect populations (pest and parasite).

The Northeastern Forest Insect Work Conference was initiated in 1968 as an outgrowth of the Northeastern Forest Pest Council. It is an unstructured organization, with no officers or treasury. Responsibility for organizing each conference rotates between federal, university, and Canadian sponsors; the responsibility is strictly voluntary. Attendance is usually between 50 and 60; in 1975, we had approximately 80.

Why the large attendance? I think it may be related, in an abstract way, to two of the main workshop topics: kairomones and the gypsy moth RD&A program. The word kairomone is derived from the Greek word "kairos," which denotes the senses of opportunistic and exploitative. A kairomone is a behavioral chemical utilized in a beneficial way by the receiver, usually at the expense of the emitter. Kairomones mediate the positive responses of predators to their prey, herbivores to their food plants, and parasites to their hosts. I suggest that the gypsy moth program fits the role of the emitter; emitting ways and especially means ($) for solving a variety of economic and social problems directly related to the scourge of the northeastern woodlands, the gypsy moth.

The program stimulated a positive response, in an opportunistic sense, to discuss the ways and means of solving problems. The workshop participants received the message and responded accordingly. In some cases, it seems, the message and response was instantaneous, leaving little time for advance communication with the host. Considering the checks and balances built into the program, we can expect the emitter, in this case, to gain as much as is expended; the adaptive advantage is obvious.

Our speakers and workshop leaders responded to the problems and kept the communication open and running smoothly. In particular, our thanks go to Charlie Parencia for the last minute pinch-hitting as the lead-off speaker. His paper on the "RD&A in the Boll Weevil Pest Management Program" stimulated our thinking about the present concepts of forest insect RD&A programs and what might be expected once the ways and means for accomplishing the application phase are decided upon.

We had two other excellent invitational papers: "Kairomones and their Role in Pest Management" by W. J. Lewis, Southern Grains Insect Research Laboratory, Tifton, Georgia; and "Gypsy Moth Research, Development and Applications Program: Structure, Objectives, and Direction" by Thomas McIntyre, Gypsy Moth Program Manager, Hyattsville, Maryland.

The workshops were organized and chaired by Drs. Marjorie Hoy (Parasite Evaluation and Management), John Podgwaite (Pathogens, Field and Laboratory), Robert Wilson (Sampling), Gerry Lanier (Behavior Mediating Chemicals), and David Leonard (Open Session). Kathy Shields did a super job organizing a "Demonstration of Equipment and Techniques" session and in addition worked on the Conference Committee with Bert Godwin, Kathy McManus, and myself. Our thanks to all the others who made the Conference go—particularly the participants!

Success of a workshop must ultimately be evaluated by each participant. As organizers we choose to use verbal participation as an index of success — and there was plenty of that!

THE PILOT BOLL WEEVIL ERADICATION EXPERIMENT

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ABSTRACT. The Pilot Boll Weevil Eradication Experiment was conducted cooperatively with 16 federal, state, and cotton-industry agencies from July 1971 to August 1973. Population-suppression components were late-season insecticide treatments, cultural practices, pheromone traps, insecticide treatment when plants began to square, in-season insecticide treatments, and release of sexually-sterile male boll weevils. After studying the data on completion of the Experiment, the Technical Guidance Committee concluded "that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by use of ecologically acceptable techniques".

THE BOLL WEEVIL, *Anthonomus grandis*, Boheman, was described in 1843 by Boheman from specimens received from Vera Cruz, Mexico. The first report of the occurrence of the boll weevil in the United States was received by the Department of Agriculture in the fall of 1894 from Brownsville, Texas. C. H. T. Townsend of the Division of Entomology, sent to Texas, found that several counties were infested and that serious damage had been caused by the pest since 1892. It is not the purpose of this discussion to give the history of the spread of the boll weevil in this country, but comments relating to early research seem to be in order.

Townsend's report about the area infested and the life history and habits of the boll weevil was published in March 1895 in INSECT LIFE. He recommended in his report that cotton stalks be destroyed to kill overwintering weevils and that a non-cotton zone be established to prevent further spread of the pest. The Department of Agriculture reported the seriousness of the pest to the Governor of Texas and urged immediate legislation to permit quarantines and remedial work.

By 1895 the boll weevil had spread as far north as San Antonio and as far east as Wharton, Texas; and 1898 was an especially bad year for boll weevils. The Legislature of Texas therefore made an appropriation for research and appointed a state entomologist to investigate means of control. The work on the boll weevil by the Division of Entomology of the Department of Agriculture was therefore discontinued at the end of that season.

Nevertheless, the boll weevil continued to spread; and it was not long—1901—before other states were threatened with invasion. Congress therefore made a special appropriation to support research designed to discover a means of preventing further spread. The resulting program was directed by W. D. Hunter. In 1908, Hunter demonstrated the cultural methods of controlling the boll weevil that had been developed by and were recommended by the Division of Entomology on eight cooperating farms. These farm demonstrations developed into the Farmers' Cooperative Demonstrations of the Bureau of Plant Industry and later into the present Extension Service of the Department.

A laboratory was established at Victoria, Texas, in 1902. This work was moved to Dallas, Texas, in 1905 and from Dallas to Tallulah, Louisiana, in 1909. There it remained until 30 June 1973.

The development of materials capable of controlling the boll weevil is of considerable interest, but time does not permit more than a brief discussion here. Paris green was tested in 1896, but it was not an effective material. In 1908, lead arsenate was formulated as a dust and at first seemed a promising supplement to cultural methods of controlling the boll weevil. However, results were erratic, and the method was not recommended by the Bureau nor used extensively by growers.

Breakthrough

The first breakthrough came when the then new insecticide, calcium arsenate, was used in field tests against the boll weevil in 1916. Although problems with formulation were encountered, sufficient progress had been made by 1921 so that the material was tested in several sections of the Cotton Belt by Tallulah Laboratory personnel. Machines for applying the material were developed at the same time.

The next step in boll weevil control was the application of calcium arsenate dust from airplanes. The use of airplanes was suggested by the success the Ohio Agricultural Experiment Station achieved with aerial applications of lead arsenate for control of catalpa sphinx, *Ceratomia catalpae* (Boisduval), in 1921. However, the first such efforts against cotton insects were made against the cotton leafworm, *Alabama argillacea* (Hübner), in 1922. Thereafter, this method of application rapidly became widespread, and commercial companies soon maintained fleets of airplanes for use in controlling the boll weevil and the cotton leafworm.

Calcium arsenate dust and its application via aircraft was a major breakthrough in boll weevil control, but the insecticide was never widely accepted because its use often caused the development of infestations of the cotton aphid, *Aphis gossypii* (Glover). This pest, if uncontrolled, would cause damage sufficient to offset any benefits obtained by controlling the boll weevil. Nicotine sulfate was developed as an aphicide, but it was difficult and unpleasant to formulate and apply; and it never gained wide acceptance.

The next major breakthrough was the development of organochlorine insecticides. However, the first of them, DDT, did not control the boll weevil. Only when BHC, toxaphene, aldrin, dieldrin, and heptachlor were developed did the growers have more efficient insecticides than calcium arsenate. When these effective materials were mixed with DDT, the mixture controlled both the bollworm, *Heliothis zea* (Boddie), and the boll weevil; and parathion could be used as an aphicide when needed. Thus, once low-pressure low-volume sprays had been developed, growers and researchers felt that the situation was well in hand.

Era of Apprehension

Unfortunately, the era of control with organochlorine insecticides was short-lived. By the mid-1950s the boll weevil had developed resistance. However, in the meantime, methyl parathion, and later azinphosmethyl, were developed for control of the boll weevil.

The threat of resistance therefore created an era of apprehension. Spokesmen for the cotton producers repeatedly emphasized that the survival of the industry depended on adequate research designed to strengthen the ability of U.S. producers to compete for markets. Leading scientists and spokesmen for industry agreed that the presence of the boll weevil in cotton-producing areas posed a major and costly problem for the cotton industry and that research support was an urgent need. As a result, in the Agricultural Appropriation Report for fiscal-year 1959, both the House and Senate Agriculture Committees requested the Secretary of Agriculture to review the boll weevil problem and submit a report on research and facility needs.

The Office of the Secretary appointed a working group consisting of E. R. McGovran of the Cooperative State Research Service, USDA; H. G. Johnston of the National Cotton Council of America; and E. F. Knipling (chairman) and C. R. Parencia (secretary), both of Agricultural Research Service, USDA, to study the problem and to (1) develop information on current research programs devoted to boll weevil investigations by state, federal, and private industry; (2) determine the needs for an overall comprehensive research program; and (3) determine the broad areas of research that would be appropriate for federal attention and support in an effort to help meet the overall needs.

The Working Group on Boll Weevil Research Programs made its study and submitted its report dated 30 December 1958. The study culminated in the appropriation of funds by Congress for the establishment of the Boll Weevil Research Laboratory at State College (now Mississippi State), Mississippi, and the strengthening of ongoing research programs at the Cotton Insect Research Laboratories at College Station, Texas; Baton Rouge, Louisiana; and Florence, South Carolina. The new research facility at Mississippi State was dedicated in a formal ceremony in March 1962. Research on the boll weevil was simultaneously strengthened in several of the state agricultural experiment stations.

Significant research findings resulting from the expedited research on the boll weevil were: (1) Techniques for mass-rearing the boll weevil; (2) development of the reproduction-diapause control program; (3) development of ultra-low-volume spray applications of insecticides; (4) development of the systemic insecticide, aldicarb, that controls the boll weevil; (5) finding that the male boll weevil emits a pheromone that attracts females and also acts as an aggregant; (6) identification and synthesis of the attractant, grandlure, and development of traps baited with it for capturing boll weevils; (7) progress in development of a chemosterilant making the male-sterile release technique feasible; (8) use of trap crops treated with aldicarb in furrow and as a sidedressing together with grandlure bait in reducing overwintered boll weevil populations; and (9) progress in the development of a frego bract cotton with considerable resistance to the boll weevil.

In recognition of the importance and urgency of eliminating the boll weevil problem as soon as it became technically and operationally feasible, the National Cotton Council of America in its 1969 annual meeting established a Special Study Committee on Boll Weevil Eradication. The Special Study Committee met in Memphis, Tennessee, on 6 May 1969 to review the status of current knowledge on boll weevil suppression measures and to consider actions that should be taken in efforts toward the elimination of the boll weevil as a pest of cotton. The chairman of the Special Study Committee appointed a subcommittee to select areas representative of boll weevil conditions in the southeastern, southern, and southwestern areas of the Cotton Belt that would be suitable for undertaking large-scale experiments to determine if boll weevil eradication was feasible with currently available suppression techniques. The subcommittee made its study and prepared a report dated 15 August 1969, which was presented to the Special Study Committee on Boll Weevil Eradication in Memphis, Tennessee, on 16 September 1969. It recommended that a pilot boll weevil eradication experiment be conducted beginning in calendar year 1970 in an area centered in Southern Mississippi and including adjacent cotton areas in Alabama and Louisiana.

Experiment Financed

The Special Study Committee accepted the recommendations of the subcommittee, and its representatives met with Department of Agriculture officials to discuss ways of financing the experiment. A decision was made that the project would be financed by $1 million from ARS (later with APHIS), $500,000 from CSRS, and $500,000 from industry, Cotton Incorporated, for each of 2 years. Mississippi was to provide a rearing facility. After a detailed study of the area was made, the estimated cost of the experiment was $2.5 million. Since only $2 million was available, the experiment was delayed for a year or until the needed additional funds could be obtained. However, in 1971 the new cotton program resulted in a considerable reduction in the cotton acreage to be planted, making it possible to start the experiment with available funds. The director of science and education appointed a technical guidance committee for the pilot boll weevil eradication experiment.

The experiment got under way in July 1971. It was conducted cooperatively with the departments of agriculture, experiment stations, and extension services of Mississippi, Louisiana, Alabama, and Texas; with Cotton Incorporated and the National Cotton Council representing the industry; and with USDA's APHIS, ARS, CSRS, ASCS, and ES.

The reproduction-diapause phase of the experiment was carried out in the fall of 1971. Unfortunately boll weevil populations were very heavy; and as a result of the mild winter, survival of boll weevils was high. A trap crop treated with aldicarb was planted in each field in the eradication and first buffer areas, and pheromone traps at the rate of two per acre were placed around each field in 1972. An insecticide application was made when plants began to square. A period of dry weather resulted in late emergence of weevils from hibernation sites, leaving too many weevils in the fields for the sterile-male releases to be effective. Five in-season applications of azinphosmethyl were made, followed with 13 applications for reproduction-diapause control. By October adults were too scarce to be detected. Pheromone trap catches in the spring of 1973 indicated very low surviving populations in the eradication and first buffer areas. Release of sterile males began in early June, but rearing problems made it necessary to reduce releases to 50 per acre instead of the hoped for 100 in the eradication area and extending only 5 miles into the first buffer area. It was originally planned that both areas receive 100 sterile males per acre per week. Fields with infestations in the remaining first buffer fields were to be treated with insecticides. Only 33 of the 236 fields were found to be infested in the eradication area, and they were in the northern zones nearest the first buffer. Strong evidence indicated that the problem was caused by migration from the second buffer, where overwintering populations were considerably higher. The infested fields were treated at 3-day intervals with azinphosmethyl. As a result of these treatments, reproduction could not be detected in 32 of the 33 fields at the end of the experiment. The infestation in the one field was not detected until the last week of the experiment, so insufficient time did not permit the total elimination of reproduction in it.

The experiment was terminated on 10 August 1973. The Technical Guidance Committee met on 30 August to evaluate results obtained in the experiment. After studying the data, it concluded ". . . that it is technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques that are ecologically acceptable".

The National Cotton Council's Special Study Committee for Boll Weevil Eradication met in Memphis, Tennessee, on 10 January 1972 to review the progress and status of the experiment. The Committee expressed a need for a comprehensive eradication plan that would outline areas for initiation and subsequent target zones, timetables, probable costs, program requirements, operational arrangements, and the like. The chairman appointed a technical committee to develop a plan for overall boll weevil eradication.

Though two preliminary meetings were held in November 1972 and early January 1973, the work of the Committee did not gain impetus until results of the experiment became available at the end of August. An overall Plan for a National Program to Eliminate the Boll Weevil from the United States was presented by the technical committee to the Special Study Committee on 4 December 1973. It was accepted and in turn was presented to the Secretary of Agriculture on 12 December. In the Agricultural Act of 1973 the Secretary had been instructed to carry out elimination programs for the boll weevil, pink bollworm and other cotton insects if he determined that it was feasible to do so. The elimination plan became quite controversial in the scientific community for various reasons. Finally, an agreement was reached to conduct an eradication trial on some 100,000 acres in northeastern North Carolina and Virginia. The Department supports the trial, but it was not funded for fiscal-year 1976.

KAIROMONES AND THEIR ROLE IN PEST MANAGEMENT

by W. J. LEWIS, RICHARD L. JONES, DONALD A. NORDLUND, *and* H. R. GROSS, JR., *Southern Grain Insects Research Laboratory, USDA Agricultural Research Service, Tifton, Ga. 31794.*

ABSTRACT. Chemical cues emanating from the host insects and acting by themselves or together with host-plant components appear to be the key factors governing host-location by parasites. A summary-analysis of the studies of these kairomones, their involvement in the behavior sequence of host selection by parasites, and the basis for their potential employment in pest management are presented.

MANY INVESTIGATIONS, beginning with an observation by Thorpe and Jones *(1937)*, have demonstrated that the behavior of parasitic insects is influenced in various ways by chemicals produced by their hosts. One of the most interesting aspects of the behavior of parasites and the major determinant of their efficiency as a control agent are the behavioral patterns involved in host selection.

Salt *(1935)*, Flanders *(1953)*, and Doutt *(1959)* separated host selection by parasites into essentially four consecutive processes. These steps are: host-habitat finding, host finding, host acceptance, and host suitability. Our discussion will deal primarily with the first two steps of this process, which we will consider collectively as host location.

In the studies of entomophagous insects at our laboratory during the last few years, we have placed a great deal of emphasis on kairomones. [Kairomones are chemical messengers released by an individual of one species that induce a behavioral or physiological response in an individual of another species that derives adaptive benefit *(Brown et al. 1970)*].

The purpose of this presentation is to summarize these studies and then to analyze their overall meaning.

Demonstration and Description of Response to Kairomones

The initial studies involved the braconid, *Microplitis croceipes* (Cresson), an important parasite of the larval stage of the corn earworm, *Heliothis zea* (Boddie) *(Lewis and Jones 1971)*. The ovipositing female parasites use fecal and other frass material voided by the hosts as a mediator for finding the host larvae. Contact with the frass results in an intensive host-seeking response involving a thorough examination of the surrounding substratum with their antennae in search of a host.

The minute trichogrammatid parasites of lepidopteran eggs, *Trichogramma* spp., were found to orient to chemicals left by moths during oviposition. Salt *(1935)* and Laing *(1937)* reported that size, shape, and color of eggs were criteria used by ovipositing females of *Trichogramma evanescens* Westwood for selecting hosts. Salt *(1935)* demonstrated that host eggs have no characteristic of themselves that allows the parasite to find them from a distance and that sight of the eggs (2-3 mm) was the method of perception. However, Laing *(1937)* demonstrated that parasites did perceive an odor left by the adult moth. Our studies have demonstrated that the *Trichogramma* do respond to kairomones from the moths and that these kairomones are very important parts of host location by females of *T. evanescens (Lewis et al 1971)*.

Differential Response to Various Host Species

Parasites usually exhibit an attack preference for one host species over another when more than one potential host species is available. The response of *M. croceipes* females to larval feces of various lepidopteran species was evaluated *(Lewis and Jones 1971)*. Intense responses comparable to those from *H. zea* were elicited by feces of *Heliothis virescens* (F.). *Heliothis virescens* is a frequent host for this parasite. Definite but considerably weaker responses were elicited by feces from larvae of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith); the beet armyworm, *S. exigua* (Hübner); and the cabbage looper, *Trichoplusia ni* (Hübner); all three of which *M. croceipes* will sting, but on which development does not occur. No response was obtained to feces of the almond moth, *Cadra cautella* (Walker) or the Indian meal moth, *Plodia interpunctella* (Hübner), neither of which is stung by females of *M. croceipes*.

Ashley et al. *(1974)* demonstrated in field-cage studies that *Trichogramma pretiosum* Riley had a constant preference for *H. zea* eggs over *T. ni* eggs, in that higher numbers of *H. zea* eggs were parasitized, even when *T. ni* eggs were more abundant. We conducted studies to determine the role of kairomones in determining this higher attack of *H. zea*, and found that this strain of parasites was more efficient at finding eggs associated with kairomones of *H. zea* moths than moths of *T. ni*.

Chemistry of Kairomones

A few of the chemical mediators involved in host selection by parasitoids have been identified and are summarized in table 1. The chemicals in the frass of *H. zea* responsible for the host-seeking response previously described for *Microplitis croceipes* were identified by Jones et al. *(1971)*. The active components, extracted from the frass of the host larvae were a mixture of 7, 9, 11, 13, and 15 methylhentriacontanes. The mass spectrum indicated the 13-methyl isomers as the most abundant. Synthesis and bioassays of the possible isomers showed that the 13-methylhentriacontane was the most active component. Females of *M. croceipes* respond to as little as 50 ng of this compound, but 150 ng is required for consistent and strong responses.

Similar chemicals have been identified as the host-seeking stimulants for *Cardiochiles nigriceps* Viereck *(Vinson et al. 1975)*. The active chemicals are the mono-methyl hentriacontanes, dotriacontanes, and tritriacontanes. The most active methyl position was 11 for hentriacontane, 16 for dotriacontane, and 13 for triacontane. Optimum activity was obtained with a 50-ng mixture of these three compounds.

Hendry et al. *(1973)* identified the host-

Table 1.—*Chemicals identified as kairomones of parasitic insects*

Parasite	Host	Type of stimulus (refer to fig. 1)	Chemical	Source	Reference
Microplitis croceipes	*Heliothis zea*	S_3	13-methylhentriacontane	Hemolymph, cuticle, frass	Jones et al. (1971)
Cardiochiles nigriceps	*Heliothis virescens*	S_3 and S_4	11-methylhentriacontane 16-methyldotriacontane 13-methyltriacontane	Mandibular gland	Vinson et al. (1975)
Orgilus lepidus	*Phthorimaea operculella*	S_3 or S_4	Heptanoic acid	Mandibular gland	Hendry et al. (1973)
Trichogramma evanescens	*Heliothis zea*	S_3	Tricosane	Hemolymph adult cuticle	Jones et al. (1973)
Archytas marmoratus	*Heliothis zea*	S_6	Protein	Feces, hemolymph	Nettles (1973)
Venturia canescens (Gravenharst)	*Anagasta kuehniella* (Zeller)	S_6	Unknown	Mandibular gland	Corbet (1971)
Itoplectis conquisitor (Say)	*Galleria mellonella* (L.)	S_6	Amino acids	Hemolymph	Arthur et al. (1972) Hedekar & Art (1973)
Cheiloneurus noxius Compire	*Coccus hesperidum* L.	S_5	Protein	Hemolymph	Weseloh & Bai (1971)

seeking stimulant of *Orgilus lepidus* Muesebeck, a parasite of the potato tuberworm, *Phthorimaea operculella* (Zell), as heptanoic acid. The parasite also responds to hexanoic acid and to a much lesser extent to valeric and octanoic acids.

The kairomones for inducing search behavior in *Trichogramma evanescens* were determined by Jones et al. *(1973)*. These parasites respond to docosane, tricosane, tetracosane, and pentacosane, constituents of the scales of its host moth. Tricosane, the most active component, increases parasitism in petri dishes when used at a rate of 6 pg/cm². Tricosane effectively increased parasitism on live plants in the greenhouse at 250 pg/cm².

The fact that these chemicals serve as kairomones is not their *raison d'etre*. However, the primary functions of all of them have not been elucidated. The saturated hydrocarbons are part of the waxy layer of the cuticle and serve as a water barrier, protecting the insect from dessication. Their presence in the mandibular gland is not as clear, but they probably lubricate the ingested food. They are also present in the hemolymph, probably serving as precursors to new cuticle formation *(Gilbert 1967)*. Synthesis probably occurs in the oenocytes *(Wigglesworth 1972)*. Their presence in frass is, in part at least, mandibular gland excretion and exuvia consumption.

The amino acids are, of course, common intermediary metabolites, and the proteins could serve any of a large number of functions. The nature of the heptanoic acid is unknown.

Manipulation of Field Behavior

Kairomones can be used to manipulate the field behavior of *Trichogramma (Lewis et al. 1972)*. A comparison was made of the incidence of parasitism on alternating kairomone-treated and control leaves in a cotton field. Leaves were selected and marked at 1-foot intervals. Every other marked leaf was sprayed with a hexane extract of *H. zea* moth scales while the alternating control leaves were sprayed with plain hexane. *T. evanescens* adults were released throughout the plot. On each day for 5 subsequent days, one

Table 2.—*Parasitism of* C. cautella *by* T. evanescens *on cotton leaves sprayed with hexane extract of moth scales and on cotton leaves for 5 days subsequent to treatment and release of parasites*

Day and treatment[a]	Host eggs					
	Dissected			Held for development		
	No.	No. dissected	No. with 1 or more parasites[b]	No. held	No. that produced parasite adults[b]	No. parasite adults produced
1 T	132	40	10	92	32	—
C	143	40	4	103	8	—
2 T	167	39	11	128	28	30
C	157	40	8	117	16	20
3 T	170	44	21	126	42	50
C	149	46	7	103	40	25
4 T	140	40	12	100	12	13
C	146	40	7	106	5	6
5 T	102	39	4	63	2	3
C	102	39	0	63	1	1
Total						
T	711	202	58 a	509	116 a	96 a
C	697	205	26 b	492	50 b	52 b

[a] T = treated, C = control.
[b] Treated and control totals, by column, not followed by the same letter are significantly different at the 5-percent level as determined by paired t-test.

host egg was placed on each of the marked leaves and re-collected after 3 hours exposure. Some of the eggs were dissected and the remainder were held to allow development of the parasites. The result was that approximately twice as many of the eggs on the treated leaves were parasitized and produced about twice as many adults for each of the 5 days subsequent to treatment and release (table 2).

Another field study was conducted to determine the effect of synthetic kairomone and to determine whether it could be used to increase parasitization by natural *Trichogramma (Lewis et al. 1975a)*. The appraisal was made on crimson clover. Ten pairs of plots 10 x 10 feet were selected, and one plot of each pair was sprayed with tricosane at a rate of 1200 mg/acre. Then 75 eggs of *H. zea* were placed in each plot and re-collected after 24 hours exposure. The parasitization, all due to naturally-occurring *Trichogramma* spp., was significantly higher in the treated plots (13 percent) than in the control plots (4 percent). Positive results have been obtained with as little as 150 mg/acre. Similar results were obtained against naturally deposited eggs.

Mechanisms Causing Increased Parasitization

Studies were made to elucidate the behavioral modifications causing the increased parasitization by *Trichogramma (Lewis et al. 1975b)*. The kairomone serves as a sign stimulus to activate a host-seeking behavior resulting in more efficient location of eggs in areas with the kairomone. The kairomone did not have the effect of an attractant, nor did it arrest them only to the substrates possessing the kairomone. Therefore, the limitations of confusion and disorientation did not occur.

Also in the plots having the appropriate kairomones with the proper distribution, better retention of the parasites in the target area resulted from the host-seeking behavior being continually reinforced.

In addition, there was a better distribution of the parasite eggs among the host eggs (less duplication) in plots treated with kairomones as compared to control plots. The presence of the kairomone on the surrounding plant surfaces probably induces the ovipositing females to depart more rapidly from host eggs that they have stung and to go in search of other hosts. The absence of the kairomone from the surrounding substratum would result in the wasps lingering on and repeatedly stinging each host that it found.

Interpretation of Host-Location Sequence

A diagram of what we consider to be the basic pathways of host location and selection is presented in figure 1. The solid lines show the processes that occur if the necessary stimuli are provided at each step. The dotted lines show the alternative processes that occur if the necessary stimuli for the subsequent step are not present. This diagram is a generalization and includes the basic components. Additional substeps and minor alternative pathways are involved and can be incorporated with the discussion of an individual species. For a detailed discussion of this sequence, refer to Lewis et al. *(1975b)*. For our purpose, presently we can say that the host-selection process consists of a sequence of behavior acts (fixed action patterns) each of which must be released by the appropriate releasing stimuli. An analysis of this sequence can be of great importance in identifying key points for parasite manipulation in pest-management programs.

The T_3 and T_3 transitions and the associated stimuli (S_3: frass, moth scales, decomposition products, or some other cues associated with the presence of hosts in the environment) between scanning of the habitat and the more thorough investigation of host trails within the habitat are the processes of primary interest in our studies of kairomones and their use in pest management. In order for females of insect parasites to remain and effectively search a desired target area, necessary stimuli (S_3) to produce the T_3 transition must be provided. Contact with the mediator that releases this behavior pattern must occur periodically to reinforce

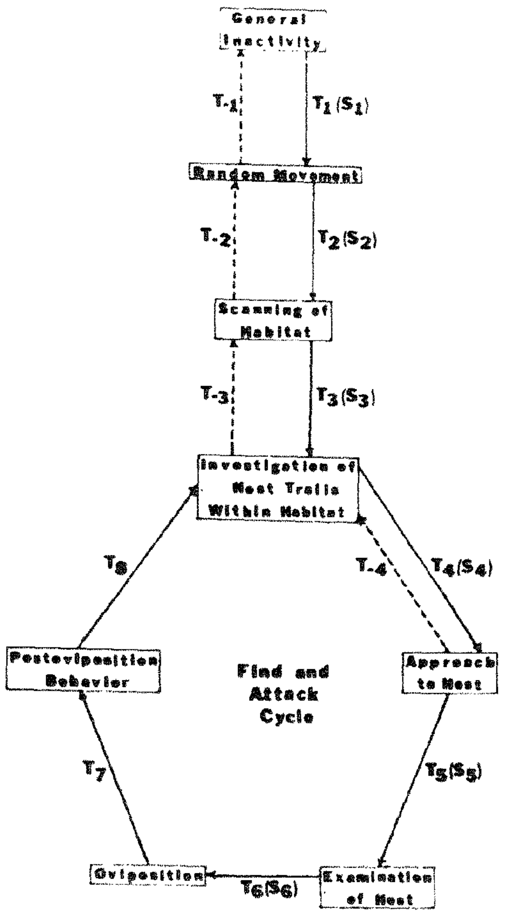

Figure 1.—Basic sequence of host-finding activities by females of parasitic insects:

T_1 to $_8$ and T_{-1} to $_{-4}$ = transitions among the indicated behavioral acts.

S_{1-6} = stimuli releasing the indicated behavioral patterns.

S_2 = olfactory, visual, and physical cues associated with host plants or other habitats.

S_3 = primarily chemical cues from frass, moth scales, and decomposition products associated with the presence of host insects.

S_4 = olfactory, visual, auditorial, and other chemical or visual cues from host insect.

S_5 and $_6$ = olfactory, tactile, auditorial, and/or combination of these cues from host individual.

and maintain the process. Lack of sufficient reinforcement otherwise allows the T_{-3} reversion to general scanning and a loss of the parasite from the target area. Such an adaptation is obviously of importance to the parasite in nature to prevent them from searching in areas where there is a lack of or too low densities of the appropriate host.

The ability to manipulate the behavior of parasites at this point of the host-finding sequence is obviously of great potential importance for more effective utilization of parasites in pest-control programs.

Prerelease Stimulation Principles

Successful establishment and retention of entomophagous insects in target areas is of foremost concern in making augmentative releases. This involves overcoming the insect's innate tendency to escape and disperse upon release, as well as releasing a host-seeking behavior that will predominate until the parasite becomes established within the habitat. Kairomones as host-seeking stimulants can play a vital role in accomplishing this desired effect.

Kairomones were evaluated by Gross et al. *(1975)* as sign stimuli at time of release to determine whether the egg parasites, *T. achaeae* Nagaraja and Nagarkatti and *T. pretiosum*, and the larval parasite *M. croceipes* could be stablized and oriented in a host-seeking pattern, thus increasing their frequency of retention in the target area and thereby improving their overall efficiency.

The results obtained with *T. achaeae* can be taken as an example. *T. achaeae* were placed in jars, the inner surfaces of which had been treated with tricosane at the rate of 1μg/30 cm^2. The parasites were held in these jars for 5 minutes just before release. Controls were held in untreated jars in a similar manner. Equal numbers of treated and control *T. achaeae* were released in separate plots of whorl-stage corn, and the parasitism was monitored for the subsequent 24 hours. The prior exposure to the kairomone resulted in increases in parasitism from 10 to 80 percent (table 3). Thus activation of the parasites before release results in an improved performance in the target area.

Table 3.—*Comparative parasitism of eggs of* H. zea *by tricosane stimulated and non-stimulated* T. achaeae *released in field plots of whorl stage sweet corn*

Item	Percentage of eggs parasitized at day —							
	1	2	3	4	5	6	7	8[a]
Stimulated	53.8	37.6	60.3	10.0	4.3	3.6	22.1	44.6
Non-stimulated	48.5	21.4	42.3	7.4	2.4	4.7	14.8	51.0
Difference	8.0	T=2.446**		—	—	—	—	—

[a] Day 8 not included in the statistical analysis.
** Significant at the 0.01 level of probability.

Similar results were obtained with *T. pretiosum* and *M. croceipes.*

Effect on Longevity and Total Productivity

Studies presented demonstrate that treatment of an environment with the kairomone increases the rates of parasitism in that area for several days after application. However, it is important to consider the effect of continuous exposure to the kairomone on the total productivity and/or longevity of the ovipositing parasite, and as to the possibilities of causing habituation or related effects by getting the supply of kairomone out of balance with the host supply.

Studies were conducted by Nordlund et al. *(1975)* to examine the effects of kairomones on productivity and longevity. Pairs of freshly emerged *T. pretiosum* (1 male and 1 female) were containerized in 25 x 200-mm test tubes (1 pair/tube), and each tube was designated as treated or control. Eggs of *H. zea* were glued on 20 x 160-mm strips of paper (20 eggs/strip), and one strip was placed in each tube. The strips for the treated tubes were sprayed with the standard moth scale extract; the control strips received no spray. At 24-hour intervals, the strips were exchanged and the condition of the parasitoids was determined. The strips removed daily were monitored to determine the percentage of parasitization and the progeny produced.

Constant exposure to the kairomone actually increased longevity. The mean longevity for females was 10.6 (±1.63) for the control and 12.2 (±1.6) for the treated females (P=0.01). Ashley et al. *(1974)* found that *T. pretiosum* females lived longer when provided naturally deposited *H. zea* versus *Trichoplusia ni* eggs for hosts and suggested the difference may have been the different stimuli received from the two host species by the ovipositing parasite.

Data demonstrate that the daily level of parasitization was higher in the treated tubes (50.4±2.9) than in the control tubes (43.0±2.5). Also, the total progeny produced was higher in the treated tubes (110.8±10.6): 54.2 males and 56.6 females/tube as compared to the control tubes (80.6±7.7), 37.9 males and 42.7 females/tube.

Nordlund et al. *(1975)* also examined the possibility of habituation in these tubes where they were in constant exposure with the kairomone in the absence of eggs. Habituation did not occur when they were placed under such conditions for 3 days and they continued to exhibit a response to the kairomone.

Summary and Conclusions

The behavior patterns involved in the host or prey selection of entomophagous insects are the major determinants of their efficiency as a controlling agent.

It has become increasingly evident that these behavioral patterns must be better understood and that techniques developed for controlling them in order to increase the dependability of entomophages in pest-management programs. It is not enough to simply release the agent in large numbers. We must have the ability to adequately select the proper species or strain and then manage their dispersal and activity so as to retain them in the target areas and maintain effective activity.

Studies of kairomones have helped develop a better understanding of the overall host-selection sequence of insect parasites. The kairomones acting as stimuli in the host-finding process offer good potential as guides for selecting appropriate species and strains for colonization and for adding greater versatility in their application. Several avenues for the use of kairomones in importation, conservation, and augmentation programs appear worthy of consideration. A brief summary of their potential utilities in local and regional augmentation programs are as follows:

A. Local Programs:
   1. Prestimulation of released beneficial insects to stabilize and orient them at time of release.
   2. Treatment of plant surfaces for stimulation of natural and/or released entomophages.
      a. Supplying appropriate chemical from host or prey insect to elicit and maintain effective search.
      b. Supplying appropriate chemical from host plant for intercepting and activating search.
   3. Integrating kairomones with food sprays and artificially supplied host or prey insect material.

B. Regional Program — Application of appropriate kairomone to selected host plants throughout an area for suppression of total pest population by:
   1. Decrease of early-season pest buildup by improving the activity of the predators and parasites.
   2. Increasing the production of parasites as a result of higher parasitism level.
   3. Stepped-up development of predators as a result of increased feeding.

Further studies of these kairomones should continue to yield an improved understanding of parasite-host relations and provide a greatly improved basis for the use of parasitic insects in pest-management systems.

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GYPSY MOTH RESEARCH, DEVELOPMENT, AND APPLICATIONS PROGRAM: STRUCTURE, OBJECTIVES, AND DIRECTION

by THOMAS McINTYRE, *program manager, U.S. Department of Agriculture Gypsy Moth Research, Development, and Applications Program, Washington, D.C.*

ABSTRACT. Because of the urgent need to control forest insect pests, a research-and-development program was established to accelerate research to provide control technology. The facilities, objectives, funding, and organization of the program are described.

IN 1973 THREE INSECTS — the Southern pine bark beetle, the gypsy moth, and the Douglas-fir tussock moth — were epidemic in the South, Northeast, and Northwest respectively. Outbreaks of these pests can be expected to continue, although intensity and extent of infestation will vary considerably in place and time.

Secretary Butz and Assistant Secretary Long of the U.S. Department of Agriculture became thoroughly familiar with these major forest pest problems. Review showed that effective strategies and techniques for dealing with these insects were lacking or inadequate. Further study showed that resources available within the Department were not adequate to provide the required pest-management techniques within a reasonable time.

Recognizing the urgent need to control these insects and prevent similar outbreaks in the future, Assistant Secretary Long asked four federal agencies — the Animal and Plant Health Inspection Service, the Agricultural Research Service, the Cooperative State Research Service, and the Forest Service — to develop plans for a research-and-development program that would provide the needed control technology. It was requested that these programs be structured so that specific objectives could be met in 4- or 5-year programs. It was determined that the longer research period would be required for the Southern pine bark beetle effort.

Staff specialists in Washington, D.C., and from the field, including scientists from several universities, developed proposed research programs outlining specific objectives and including estimated budgets. I will outline the proposed programs and the funds requested to complete the research. The structuring for these research-and-development efforts for the three insects is identical. Therefore I will not outline details on the three pest problems, but will limit my remarks to the gypsy moth program.

The present funding for the ongoing gypsy moth research-and-development program is \$2.3 million. Examination of the resources available indicated that they were not adequate to provide the needed control technology within a short time. Considerable acceleration of the program was indicated.

An analysis of available resources revealed research-and-development capability at the following faciities:

Forest Service laboratories. — Hamden, Connecticut; Delaware, Ohio.

Forest Service pest-control centers. — Hamden, Connecticut; Upper Darby, Pennsylvania.

Agricultural Research Service Laboratories.—Beltsville, Maryland; Newark, Delaware; Serves, France; Tokyo, Japan.

Animal and Plant Health Inspection Service Laboratories.—Otis Air Force Base, Cape Cod, Massachusetts.

Universities in the Northeastern United States

Accelerated Program of Attack

Here is a summary of the program objectives and expected results in the accelerated gypsy moth research-and-development program:

Objectives:

- Monitor and predict moth populations and damage
- Develop materials and strategies for suppressing moths
- Provide integrated pest-management strategies

Expected Results:

- Methods for detecting, evaluating, and predicting changes in moths and damage
- Methods for using toxicants, microbials, behavioral materials, parasites, predators, pathogens, and sterile males
- Technology for managing or eradicating moths in chronic infestations and isolated areas

To achieve the objectives and provide the anticipated results, a 3-phase strategy/activities/cost program was developed:

	Million dollars
PHASE I — Predicting populations and impacts:	
Predicting populations	2.0
Predicting impacts	1.4
Integrating changes and impacts	0.7
	4.1
PHASE II — Developing techniques for control of moths:	
Parasites and predators	2.0
Microbials	2.3
Disparlure	3.9
Toxicants	1.3
Sterile males	.2
Mass rearing	.8
Chemostimulants	.5
	11.0
PHASE III — Providing integrated pest management systems:	2.3
Total, FY '75-'77	17.4

Assistant Secretary Long and the support staff met in the summer of 1974 with Office of Management and Budget personnel and congressional committees to deal with matters involving funding of the three accelerated insect research-and-development programs. Funds were obtained for each of the three programs, and the table outlines budgets for the Combined Forest Pest Research and Development Programs.

Organizational Structure

Interagency and university involvement in the forest-insect pest programs suggested the need for new organizational structures. Key points are the Program Manager and the Program Board.

The Board is composed of the agency heads from the Forest Service, Animal and Plant Health Inspection Service, Agricultural Research Service, Cooperative State Research Service, and a representative from the Association of State College and University Forestry Research Organizations. The Program Board will be expanded to provide for several more members to obtain adequate inputs from individuals with specialized interests. The Deputy Assistant Secretary for Conservation, Research and Education (currently Mr. Vander Myde) chairs the Board. He is assisted by a staff officer who carries out staff functions. Keith R. Shea, formerly in charge of forest insect and disease research in the Forest Service, was appointed to this position.

The Program Manager is considered the key to eventual success of these accelerated research-and-development efforts. The Program Manager reports directly to the Board. He has operational responsibility for project planning, implementation, review, and control. Personnel, funds, and facilities are supplied by an appropriate administrative management unit of the Forest Service. The Program Manager consults on major decisions with the agencies or institutions providing resources.

The Program Manager is authorized to use all the instruments of management available to USDA Agencies. In addition to in-house mechanisms, these include cooperative agreements, grants, and contracts with universities, state governments, and private

Table.—*USDA forest pest programs, budget summary*

[In millions of dollars]

Fiscal-year	Douglas-fir, tussock moth	Gypsy moth	Southern pine bark beetle	Total
1975	2.0	4.8	2.5	9.3
1976	3.0	7.9	4.4	15.3
1977	2.7	6.0	4.3	13.0
1978	.5	.2	4.1	4.8
1979	—	—	4.3	4.3
Total	8.2	18.9	19.6	46.8

institutions. Funds are allocated in accordance with activity needs regardless of source. Support provided to the universities is at least equal but not limited to funds appropriated to the Cooperative State Research Service for this project.

PARASITE EVALUATION AND MANAGEMENT

by MARJORIE A. HOY, *the Connecticut Agricultural Experiment Station, New Haven; now a research entomologist, Forest Insect and Disease Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, Conn. 06514.*

THE WORKSHOP on Parasite Evaluation was attended by approximately 60 people the first day and by about 40 people the second day, surely an indication of the interest held by many in gypsy moth parasites. The agenda was followed fairly closely by the contributors, and questions and answers from the audience were numerous.

The invited contributors were: Jack Coulson, Chief, Beneficial Insects Introduction Research Laboratory, USDA, ARS, Beltsville, Md. 20705; Larry Ertle, Quarantine Officer, USDA, ARS, Newark, Del. 19713; Timothy Tigner, Division of Forestry, Commonwealth of Virginia, Charlottesville, Va. 22903; Ronald Weseloh, The Connecticut Agricultural Experiment Station, New Haven, Conn. 06504; Mark Ticehurst, Bureau of Forestry, Middletown, Pa. 17057; Thomas ODell, Northeastern Forest Experiment Station, U.S. Forest Service, Hamden, Conn. 06514.

The purposes of the workshop as seen by the chairwoman were twofold: (1) to impart information about work going on in various laboratories and organizations, and (2) to attempt to reach a concensus about the direction the new gypsy moth parasite program should go, particularly with reference to priorities in foreign exploration.

With respect to goal 1, I believe that much information was exchanged between various people working with gypsy moth parasites. Jack Coulson discussed problems and limitations during foreign collection and quarantine handling due to the limitations on funds and personnel. Larry Ertle noted that his capacity to provide detailed information about exotic species during quarantine was severely limited by the huge workload he was inundated with each season.

Jack Coulson placed considerable emphasis upon receiving information from research people involved with gypsy moth parasites. Specifically, he would be glad to have a foreign data sheet with desired information to give to foreign field personnel. Furthermore, he would like to have information from people interested in working with gypsy moth parasites and a return from them of the information they are able to obtain. It appeared that there are increasing numbers of research people interested in various types of evaluation of new exotic gypsy moth parasites.

Considerable discussion concerned multiple vs. single introductions. A consensus seems to be that single introductions are the extreme at one end, while the extreme multiple system is not as productive as something in between; i.e. the chairwoman, at least, felt that people attending might vote for increased study of the new exotics prior to importation, and a moderately selective introduction scheme.

The Parasite Management Workshop on Thursday morning was made available to the group to continue the discussion. Thus, part II of the agenda was covered then. Mark Ticehurst was able to give a clear, concise summary of the work the Pennsylvania group is doing. Tim Tigner discussed the values of percentage of parasitism in parasite evaluation. Open discussion made it clear that percentage parasitism, while not the ideal method of evaluation, does have its uses, particularly when gypsy moth population densities, etc., are given. Certainly percentage of parasitism is sufficient to determine establishment, although its value in relation to efficacy are open to considerable debate. It may be of value also in evaluation of management techniques.

Alternative methods of evaluation were discussed by Ron Weseloh. He mentioned various sampling and behavioral analyses he has used in an attempt to evaluate several gypsy moth parasites. He also reviewed a paper by Price about predicting effectiveness through measurements of niche breadth *(Price 1972)*.

Nothing along these lines appears to have been done with gypsy moth parasites, and perhaps analyses such as these could provide valuable information. In addition, Ron tried to open the discussion up to other classical biological-control techniques and their relationship to evaluation of gypsy moth parasites. These included experimental removal of parasites; insecticidal check methods, and mechanical exclusion such as caging or hand-removal, and interference techniques. Their adaptation to gypsy moth parasites is open to question.

Finally, Tom O'Dell discussed various aspects of his and Bert Godwin's evaluations of *Blepharipa pratensis*. These include studies of behavior in the field and laboratory, including sampling methods, with the ultimate goal of sampling all stages of *Blepharipa* to develop a life table.

Assuming that the lines of communication developed and widened during the workshop are maintained during the coming year, I believe the workshop was positive— time well spent.

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FIELD AND LABORATORY IDENTIFICATION OF INSECT PATHOGENS

by JOHN D. PODGWAITE, *research microbiologist, Forest Insect and Disease Laboratory, Northeastern Forest Experiment Station, Forest Service, USDA, Hamden, Conn. 06514.*

An understanding of disease processes occurring in insects is basic to any RD&A program involved with pest management. It is of course essential to a program like the gypsy moth program that stresses the utilization of microbial agents for pest control.

The first step in the development of a microbial control agent is to find it. The next step is to identify it and determine how it kills the insect. The successful accomplishment of these steps and the other logical developmental steps (safety testing, production, field testing) depends on the utilization of a variety of diagnostic procedures and techniques.

There are of course other areas of an RD&A program where a knowledge of disease and pathogens is important; for example, in population dynamics studies, where the identification of disease conditions are necessary for building life tables. Also, the successful establishment and maintenance of insect cultures necessitates a need for diagnosing, treating, and then avoiding disease problems.

The workshop discussions focused on some of the techniques utilized to diagnose disease conditions both in the field and in the laboratory and on how these techniques are used in RD&A program studies.

Normand R. Dubois, microbiologist, USDA Forest Service, presented the general techniques of insect pathology and microbiology used to diagnose disease conditions in insects. He indicated that there are many techniques the untrained field worker can use to diagnose disease in field populations. Some rapid staining and microscopic techniques for demonstrating viruses, fungi, and bacteria were discussed.

I discussed how diagnostic techniques were used in a large-scale evaluation of disease in natural gypsy moth populations. I pointed out that certain techniques must be modified when diagnosing a large number of insects in a limited time frame, and that one must compromise some degree of diagnostic detail in order to obtain numbers that can be subjected to rigorous statistical analyses.

Finally, R. A. Dicapua, associate professor of immunology at the University of Connecticut, discussed the potential of various immunological assays for detecting preclinical cases of insect virus disease in the field. He indicated that these could be valuable tools for the accurate prediction of future populations trends.

Headquarters of the Northeastern Forest Experiment Station are in Upper Darby, Pa. Field laboratories and research units are maintained at:

- Amherst, Massachusetts, in cooperation with the University of Massachusetts.
- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.