THE ECOLOGY AND MANAGEMENT OF THE ORIENTAL COCKROACH *Blatta orientalis* L. (ORTHOPTERA: BLATTIDAE) IN THE URBAN ENVIRONMENT

by

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Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in
Entomology

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May, 1986
Blacksburg, Virginia

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(ABSTRACT)

The oriental cockroach, *Blatta orientalis* L., was found to be an important seasonal household pest. Of 151 residents interviewed in two Roanoke apartment complexes in Virginia, 90% had seen oriental cockroaches, 60% considered one oriental cockroach indoors to be a problem, and 77% had taken steps to control these cockroaches. Monitoring oriental cockroach populations indicated when and where treatment would be necessary to reduce cockroach infestations. The adult cockroach population peaked in late June and July, and declined through August and September while the number of nymphs increased. Eighty percent of all cockroaches trapped at Roanoke apartment buildings were caught at porches, the primary cockroach harborage sites. In a mark-recapture study at four apartment buildings, 50% of the resighted oriental cockroaches remained at one porch, 36% moved along one side of a building, 13% moved between the front and back of

a building, and 2% moved between two buildings. Only 1-5% of the oriental cockroaches marked outdoors were ever captured indoors.

One exterior perimeter and crawlspace application of encapsulated chlorpyrifos or diazinon in early June was the most effective insecticide treatment, reducing oriental cockroach populations by at least 85% for two months. Oriental cockroaches populations were reduced 78% and 50% two months after application of Dursban 4E (chlorpyrifos) and Combat bait trays (hydramethylnon), respectively. Structurally modifying buildings, to limit cockroach access to harborage in porch and wall voids, did not significantly ($P < 0.05$) reduce oriental cockroach populations, even one year after treatment. Structural modification was labor intensive, requiring at least eight times more man-hours per building compared to insecticide applications.

The evaniid wasp *Prosevania punctata* (Brullé) had been seen in apartments by 60% of the Roanoke residents interviewed. This wasp parasitizes and destroys the oothecae of oriental cockroaches. *P. punctata* exhibited a maximum parasitization rate of 51% for oothecae of oriental cockroaches in laboratory conditions. Three peaks of evaniid wasp field populations closely followed the rise, peak, and decline of adult oriental cockroach populations. A resident education program significantly ($P < 0.05$) reduced the percentage of residents in Roanoke apartment complexes who thought evaniid wasps were a problem or killed them. However, evaniid wasps parasitized only 15% of the field-collected oriental cockroach oothecae, significantly fewer ($P < 0.05$)

than the 36% parasitized by the eulophid wasp *Tetrastichus hagenowii*. In addition, 60% of the residents still killed evaniid wasps, despite the education program.

ACKNOWLEDGEMENTS

Research is rarely the product of one individual. The contributions of many people are responsible for making this dissertation a realization, rather than an aspiration. I am indebted to my advisor, Bill Robinson, for providing me with the opportunity to pursue a Ph.D. degree at VPI & SU, and for initiating my career as an urban entomologist. Bill Robinson and the other committee members, Jim Ballard, Robin Andrews, John Eaton, and Don Mullins, conscientiously reviewed (and re-reviewed) manuscripts, dutifully attended committee meetings, graciously provided advice, and were very supportive throughout my tenure as a graduate student. The Virginia Pest Control Association and Pi Chi Omega generously provided me with scholarship funding.

Many other individuals helped with field work and data analysis. The management and residents of RRHA apartments were very cooperative with surveys, cockroach trapping, field tests, and the education program. I am particularly thankful to Doris Workman, the Carr, Grimes, and Sexton families, and the 'Roachbuster' club (Billy, Jamie, and Kenneth) for their friendship and invaluable assistance with the studies on cockroach movement and evaniid wasps. Walter Foliaco was a competent and dependable field technician for the 1984 field season. "Dr." Rock's expertise in constructing lab and field equipment and Bill Carter's careful attention and thoroughness in repairing buildings for the structural modification test are truly appreciated. John Deighan is a saint; he wrote the Pascal computer program for analyzing the cockroach movement data. Marvin Lentner provided valuable statistical consultation throughout the course of this research, and Pat Edwards provided advice concerning survey analysis and data interpretation. Lok T. Kok and Bob Pienkowski reviewed and improved sections of this dissertation.

I am grateful to many VPI & SU graduate students for their friendship and assistance, particularly Brett Highland, Ren Wang, Joan LaSota, Karen Vail, Bonnie Dodson, Dave Byron, and last but never least, "Mr. Mapes." Above all, I thank my parents for their love, support, and acceptance of a daughter who spent three years studying cockroaches.

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Chapter I

LITERATURE REVIEW AND OBJECTIVES

1.1 DISTRIBUTION

The oriental cockroach, *Blatta orientalis* L., is one of the most common cockroach pests throughout temperate regions of the world (Cornwell 1968). In spite of its name, the oriental cockroach is believed to have originated from temperate zones in either north-central Africa (Rehn 1945) or southern Russia around the Black and Caspian Seas (Princis 1954). The oriental cockroach spread throughout Europe and reached the New World via early trade and shipping routes (Rehn 1945). Its currrent worldwide distribution was most recently reviewed by Cochran (1982).

1.2 PEST STATUS

Oriental cockroaches find harborage in basements and crawlspaces (Ebeling 1978), trash chutes (Nixon 1984), refuse dumps (Lucas 1912, 1922, Gould 1940), sewers (Anonymous 1957, Pul'ver 1973), or under debris and walkways near buildings (Shuyler 1956). This cockroach becomes a pest when it disperses from these harborage sites indoors into private homes, schools, restaurants, hospitals, and other commercial buildings (Cornwell 1968). The pest status of oriental cockroaches is based on their potential to transmit disease, damage to substrates on which they feed or defecate, and the anxiety they cause in humans.

1.2.1 Disease vectors

The oriental cockroach is an efficient reservoir and potential vector of organisms pathogenic to humans and animals (Burgess 1984). The causative agents for boils and abcesses (*Staphylococcus aureus*), typhoid fever (*Salmonella typhosa*), diarrhea (*Shigella paradysenteriae*), Bubonic plague (*Yersinia pestis*), urinary tract infections (*Pseudomonas aeruginosa*), and food poisoning (*Escherichia coli*, *Streptococcus faecalis*, *Proteus vulgaris*, *Clostridium perfringens*, *Vibrio* spp.) have been isolated from oriental cockroaches collected in sewers, hospitals, and other locations (Roth and Willis 1957, Burgess et al. 1973, Pul'ver 1973, Burgess et al. 1974, Frishman and Alcamo 1977, Cornwell and Mendes 1981). Porcine parvovirus, a viral pathogen of pigs, can be harbored in the alimentary tract of oriental cockroaches (Tarry and Lucas 1977). Cockroaches become externally or internally contaminated with pathogens by contacting or ingesting refuse, feces, sputum, and other waste matter (Burgess 1984). Burgess et al. (1974) demonstrated that the normal bacterial flora in the gut of oriental cockroaches in sewers was nearly identical to that of their surroundings. None of the human pathogenic bacteria isolated from oriental cockroaches appeared to have any deleterious effects on the insects (Burgess et al. 1973). Pul'ver (1973) reported that a high percentage of oriental cockroaches in sewers were contaminated with *E. coli* and *P. vulgaris*. Oriental cockroaches trapped and marked in these sewers dispersed to adjacent apartment houses and offices. Cornwell and Mendes (1981) isolated six species of food poisoning bacteria from oriental cockroaches collected in residential and commercial buildings; the average number of pathogenic bacteria on a cockroach's body greatly exceeded the acceptable number of organisms per cm^2 on food preparation surfaces. Humans could become infected by contacting surfaces or eating food contaminated by oriental cockroaches. The documentation of oriental cockroach involvement in outbreaks of human disease is based on circumstantial evidence (Roth and Willis 1957). Nonetheless, these cockroaches could be considered a contributory factor in the epidemiology of disease (Burgess 1984).

1.2.2 Human attitudes

Cockroaches are considered pests because of the psychological distress they cause in humans. In a survey of 3,100 randomly selected Americans, cockroaches were the least liked of 26 animals (Kellert 1980). Surveys of public housing residents in Roanoke Va., Norfolk Va., and Baltimore Md. reported that 83-87% of the respondents considered the German cockroach, *Blattella germanica* (L.), to be a serious problem (Wood et al. 1981, Zungoli and Robinson 1984) and 71% of the residents initiated control measures if five or fewer cockroaches were seen in one day (Zungoli and Robinson 1984). These surveys indicate that people have a low tolerance to German cockroaches. People are probably even less tolerant of oriental cockroaches found indoors, because these cockroaches are twice the size of German cockroaches, 3.0 cm versus 1.6 cm, respectively (Ebeling 1978). However, no surveys have been conducted to assess resident attitudes toward oriental cockroaches.

1.3 DEVELOPMENT

The oriental cockroach has a life cycle typical for cockroaches in the family Blattidae. The sex ratio of adult males to females is 1:1. Males and females mate within days after molting to adults (Willis et al. 1958). Females can reproduce parthenogenetically, but significantly fewer unfertilized eggs hatch compared to fertilized eggs (Roth and Willis 1956). Each 10 by 5 mm ootheca contains a mean of 16 eggs (Rau 1924, Gould and Deay 1940). The female carries the ootheca for about 30 hours after it is formed, then drops or attaches the ootheca, covering it with debris, in a secluded area (Gould and Deay 1940, Rau 1943). Each female produces a mean of eight oothecae (Gould and Deay 1940). Incubation time for oothecae varies from 37 days at 28° C to 81 days at 21° C (Gould and Deay 1940).

A mean of 8-15 nymphs emerge per ootheca (Gould 1940, Willis et al. 1958). Newly emerged nymphs are about 6 mm long and pale brown and become darker through successive instars (Ebeling 1978). The developmental time and number of instars for nymphs vary depending upon gender; males generally develop more rapidly than females. At 30° C, males molt 7-8 times during a developmental period averaging 146 days; females molt 9-10 times in 165 days (Willis et al. 1958). The developmental time and adult longevity decrease as the temperature increases. Gould (1940) reported that at 24° C, oriental cockroaches matured in 533 days and adults lived 110 days, whereas at 27° C, they mature in 316 days and adults live 100 days.

1.4 PROBLEMS IN COCKROACH MANAGEMENT

The oriental cockroach would appear to be an unlikely candidate for a worldwide pest. The large size of oriental cockroaches limits the cracks and crevices large enough to provide harborage. The prolonged developmental period of nymphs delays oriental cockroach re-establishment after insecticide application, and delays development of insecticide resistance. Oriental cockroaches have not been reported resistant to currently used insecticides (Cochran 1984). Lack of resistance could be due to fewer generations of oriental cockroaches, compared to German cockroaches, being exposed to insecticides in a given time period. Oriental cockroaches seem to have limited dispersal capabilities. Both nymphs and adults lack arolia, which would enable them to climb smooth surfaces (Ebeling 1978). Nymphs and adults are flightless and are more readily caught in sticky traps than other cockroach species (Moore and Granovsky 1983). Oriental cockroaches are also outcompeted by German cockroaches and American cockroaches, *Periplaneta americana* (L.), when forced to share harborages (Kanzler 1972).

The oriental cockroach is the dominant cockroach pest in Britain (Cornwell 1968) and in portions of the northwestern, midwestern, and southern United States during May and June (Mampe 1972). The seasonal pest status of the oriental cockroach coincides with the peak maturation in May and June of nymphs to adults (Rau 1924, Gould and Deay 1940).

1.4.1 Seasonal life cycle

The seasonal life cycle of the oriental cockroach is an important factor in its success as a pest. The seasonal development of oriental cockroaches is synchronized due to their behavior of overwintering in crawlspaces, under sidewalks and litter, and in other sites outside resident living areas (Shuyler 1956). Oriental cockroaches are capable of overwintering outdoors, unlike German and American cockroaches, due to their cold tolerance. In experiments in which adult cockroaches were acclimatized to 15° C then placed in 5° C, oriental cockroaches survived 21 days (Mellamby 1939), German cockroaches survived 10 days, and American cockroaches survived 5 days (Tsuji and Mizuno 1973). Oriental cockroach nymphs have been reported to survive outdoors during three winter months with mean minimum temperatures of 5° C in Britain (Solomon and Adamson 1955) and 0° C in the United States (Shuyler 1956). The seasonal decline in the adult oriental cockroach population in late summer and cockroach inactivity throughout the winter (Rau 1924, Gould and Deay 1940) may give the false impression that control has been achieved. Barak et al. (1977) reported that sticky traps effectively reduced moderate infestations of oriental cockroaches. However, their evaluation period occurred in Wisconsin from late July through October when populations would have naturally declined.

1.4.2 Dispersal

Another factor contributing to the success of oriental cockroaches as pests is their ability to move indoors when outdoor harborages become overcrowded or otherwise unsuitable. Laboratory reared oriental cockroaches remain at preferred harborages and move limited distances only when population densities are high (Denzer et al. 1985). However, laboratory reared cockroaches tend to move significantly less than field collected cockroaches, as demonstrated by movement studies with German cockroaches (Akers and Robinson 1983). The movement of oriental cockroaches (Pul'ver 1973) and American cockroaches (Eads et al. 1954, Schoof and Siverly 1954, Jackson and Maier 1954, 1961) from sewers to adjacent homes has been documented. Studies in which cockroaches were individually marked and their movements were recorded have been conducted for the German cockroach (Zungoli 1982, Runstrom and Bennett 1984) and the smokybrown cockroach, *Periplaneta fuliginosa* (Serville) (Fleet et al. 1978, Appel and Rust 1985). These studies documented German cockroach movement indoors within and between apartments, and smokybrown cockroach movement outdoors within areas exceeding 100 m^2 per cockroach. No similar studies evaluating the movement of individual cockroaches have been conducted with the oriental cockroach.

1.5 COCKROACH MANAGEMENT TECHNIQUES

1.5.1 Insecticides

Many control techniques have not been evaluated for managing oriental cockroach populations, despite the pest status of this insect. Insecticides have been used for short term reduction of oriental cockroach populations. The active ingredient used is not critical because the oriental cockroach has not been reported to be resistant to currently used insecticides. However, the formulation of insecticide may be important because oriental cockroaches prefer to harbor on damp, porous surfaces, such as concrete, where insecticides rapidly degrade. Slominski and Gojmerac (1972) reported that emulsifiable concentrate formulations of chlorpyrifos and malathion were toxic no longer than one week on concrete. Professional pest control operators generally use emulsifiable concentrate formulations for exterior building treatments to control cockroaches (Tucker 1984). Bait or encapsulated formulations of insecticides might prolong the toxicant's activity to more effectively manage oriental cockroach populations. Oriental cockroaches will consume foods imbedded in wax, an appropriate bait formulation for sewers and crawlspaces (Eversole 1971). A one-time perimeter application of encapsulated diazinon around dwellings significantly reduced American cockroaches and smokybrown cockroaches (Granovsky 1985). No field evaluations to compare the efficacy of different insecticide formulations for reducing oriental cockroach populations have been reported.

The potential of selecting for insecticide resistance in the target organism and toxifying nontarget organisms necessitates the careful and selective use of insecticides for oriental cockroach control. Although their resistance to currently used insecticides has not been reported, resistance of oriental cockroaches to DDT and chlordane was demonstrated on U.S. military bases in Germany during 1956-1959 (Webb 1961). These military installations had used DDT since 1944 to control cockroach pests. Exposure of both target and nontarget organisms to insecticides could be reduced by integrating noninsecticidal control methods into a managment program. These methods would include sanitation, trapping, structural modification, and biological control agents.

1.5.2 Sanitation

Improving sanitation to reduce the available food has been recommended for managing German cockroach populations (Wright 1979, Wood 1980). This strategy may not be effective against oriental cockroaches which forage outdoors, where naturally occurring organic matter is abundant. Periplaneta species foraging outdoors have been observed feeding on fallen flowers (Seelinger 1984), ripe figs, dead worms and insects, mammalian, avian, and reptilian feces, and the bark and catkins of pecan trees (Appel and Rust 1986). In addition, female oriental cockroaches can survive an average of 32 days given only water and no food (Willis and Lewis 1957). Oriental cockroach nymphs which have been nutritionally deprived for up to three months, can resume normal growth, attain sexual maturity, and produce viable offspring when provided with a balanced diet (Zabinski 1929).

1.5.3 Trapping

Populations of the oriental cockroach would appear to be more easily reduced by trapping than other pest species due to this cockroach's low reproductive potential and its high likelihood of being caught (Moore and Granovsky 1983). Moore and Granovsky (1983) reported a 63% reduction in oriental cockroach populations within test arenas after 14 days exposure to sticky traps, compared to 5-38% reductions in the populations of four other cockroach pest species in the same conditions. However, studies using sticky traps to reduce natural infestations of oriental cockroaches have yielded inconclusive results (Barak et al. 1977).

1.5.4 Structural modification

Structural modification, sealing cracks or openings in foundations and walls to reduce cockroach access to outdoor and indoor harborage sites, has been recommended for managing oriental cockroach populations (Piper et al. 1975, Ballard and Gold 1984). Farmer and Robinson (1984) reported the difficulty of sealing all access to harborage for reducing German cockroach populations. They observed no significant difference in the reduction of cockroach populations between uncaulked apartments and caulked apartments in which only 40% of the internal cracks and crevices could be sealed. However, sealing access to suitable harborage sites may be more practical for large cockroach species, which prefer harborages 1 cm wide, than for small cockroach species, which prefer harborages 0.5 cm wide (Mizuno and Tsuji 1974). No investigations evaluating structural modification for controlling large cockroach species, i.e. Blatta and Periplaneta, have been reported.

1.5.5 Biological control agents

Numerous potential biological control agents, such as pathogens, predators, and parasites, have been listed for oriental cockroaches (Roth and Willis 1960). Little research has been conducted on use of pathogens or predators for managing oriental cockroach populations. The fungus *Herpomyces stylopygae* Spegazzini has been identified in laboratory reared oriental cockroaches (Richards and Smith 1955) and possibly in field collected cockroaches (Ballard and Gold 1984). The fungus does not appear to cause mortality; the infection is restricted to the antennae and is lost during the molting process (Richards and Smith 1955).

Hymenopteran parasites of cockroach oothecae may have the greatest impact on oriental cockroach populations. Oothecae protected by a sclerotized capsule would appear to be the most difficult stage of the oriental cockroach to control using only insecticides. The habit of females to deposit oothecae in concealed locations and to cover them with soil and debris (Gould and Deay 1940, Rau 1943) may protect the oothecae from exposure to insecticides. In addition, the area of the ootheca contacted and age of an ootheca affect its susceptibility to insecticides (Killough 1958). Treating American cockroach oothecae with insecticides on the keel and close to cockroach emergence time has the most detrimental effect on nymphal survivorship (Killough 1958). These observations indicate that parasites which consume and destroy the contents of cockroach oothecae should be integrated into an oriental cockroach management program. The evaniid wasps Evania appendigaster (L.) (Haber 1920, Townes 1949) and Prosevania punctata (Brullé) (Edmunds 1952a, 1952b, 1953, 1954) and the eulophid wasp Tetrastichus hagenowii (Ratzeburg) (Usman 1949, Roth and Willis 1954, Piper et al. 1978, Harlan and Kramer 1981) have been reported to parasitize oriental cockroach oothecae. These three wasp species are distributed worldwide and are common in larger cities in the United States (Muesebeck et al. 1951). Evaniids are solitary parasites, with one wasp larva developing per cockroach ootheca (Edmunds 1952a). Eulophids are gregarious parasites, with numerous larvae developing in one ootheca (Roth and Willis 1954). Field surveys of Periplaneta oothecae have revealed maximum parasitization rates ranging from 46-93% (Vargas and Fallas 1974, Fleet and Frankie 1975, Piper et al. 1978, Wen-qing 1984). No surveys have been conducted to quantify the parasitization rates of oriental cockroach oothecae in field conditions.

1.6 OBJECTIVES

The Roanoke Redevelopment and Housing Authority (RRHA) in Virginia manages nine apartment complexes housing aproximately 6,000 residents. Since 1977, entomologists from Virginia Polytechnic Institute and State University (VPI & SU) have evaluated residents' perceptions, the biology, and control of German cockroaches infesting RRHA complexes (Akers and Robinson 1981, Wood et al. 1981, Farmer and Robinson 1984, Zungoli and Robinson 1984). Moderate to severe infestations of oriental cockroaches were observed around the exterior perimeter of buildings in Lansdowne Park and Lincoln Terrace and the evaniid wasp P. punctata was occasionally caught in traps placed in these buildings (W. H Robinson, personnal communication).

The purpose of the research presented here was to develop a safe, effective, economical management program for oriental cockroaches. All field research was conducted at the RRHA complexes Lansdowne Park and Lincoln Terrace. The specific objectives were to:

1) Assess resident knowledge of and attitudes toward oriental cockroaches and the evaniid wasp P. punctata;

2) Determine the distribution and seasonal abundance of oriental cockroaches and evaniid wasps;

3) Study the movement of marked, field-collected oriental cockroaches around and into apartment buildings;

4) Evaluate the efficacy and cost of several insecticide formulations and structural modification for reducing oriental cockroach infestations;

5) Evaluate P. punctata as a biological control agent for the oriental cockroach by determining the a) oviposition potential of the wasp in laboratory and field studies, and b) potential for humans to learn to tolerate the wasp.

Chapter II

DISTRIBUTION, SEASONAL ABUNDANCE, AND PEST STATUS OF THE ORIENTAL COCKROACH AND AN EVANIID WASP, *PROSEVANIA PUNCTATA*

One of the first steps for developing a cockroach management program is a survey of knowledge and attitudes of residents toward target insects (Zungoli and Robinson 1984, Robinson and Zungoli 1985). Surveys assess the resident's threshold level of tolerance, usually referred to as aesthetic injury level (AIL)(Olkowski 1974, Zungoli and Robinson 1984), for each target insect. AIL's establish the primary goal of the management program (i.e., the percentage reduction of pest populations desired by the residents). AIL's could also determine resident acceptance of beneficial insects used to control the pest species. An efficient parasite or predator would be unsuitable in an urban environment if residents would not tolerate its presence.

The entomological community in general has been reluctant to accept opinion surveys as an important research technique for urban entomologists. Critics of urban entomological survey data appear to misunderstand the role of target audience attitudes in developing pest management programs, commenting that "(the surveyors) asked the sampled population to provide subjective data instead of collecting their own data in an objective manner." Critics also appear to lack confidence in a resident's ability to provide accurate information on household insects, concluding that "a homeowner does not qualify as an expert witness" (anonymous reviewers of Ravlin and Robinson 1985).

The purpose of this study was to obtain baseline data for developing an oriental cockroach management program. Tolerance of oriental cockroaches and evaniid wasps was determined and interpreted as the residents' expectations of the pest management program. The resident survey and field collection of the cockroaches and wasps were conducted simultaneously. Perceived versus actual conditions concerning insect distribution and abundance were compared to evaluate the ability of the target audience to be an accurate source of information.

2.1 MATERIALS AND METHODS

2.1.1 Study Site

Apartment buildings used in this study were in two RRHA complexes, Lansdowne Park and Lincoln Terrace. The demographic data and economic profile of RRHA residents have been described by Wood et al. (1981). Residents of Lansdowne Park were nearly equally divided between black and caucasian; nearly all residents at Lincoln Terrace were black.

2.1.2 Survey of Attitudes of Residents

Thirty pretest surveys were conducted during the summer of 1983 at Lansdowne Park and Lincoln Terrace apartment complexes, and adjustments were made in the final questions and format. Seventy-six residents at Lansdowne Park and 75 residents at Lincoln Terrace were surveyed in August 1984. The survey was conducted as a door-to-door interview by one person. To determine the distribution of the target insects, a resident from one apartment per building was randomly selected for an interview. If an interview could not be obtained after two attempts at contact were made with this resident, a resident from another apartment in the same building was randomly selected. Fifteen of the 18 survey questions were open-ended and answers were categorized at the termination of the survey. To avoid misidentification of the target insects, the common names "cockroach" and "evaniid wasp" were not used. Instead, respondents were referred to live specimens in clear plastic vials; the insects were identified at the termination of the interview.

For the initial survey question, respondents were shown live oriental cockroaches and asked, "Have you seen these insects in or around your apartment building during the past 6 months?" To determine the distribution of oriental cockroaches, residents who had seen these insects were asked, "Where around your building have you seen them?" Residents' tolerance of oriental cockroaches was assessed by the question: "Say you are visiting someone's apartment for the afternoon, and you see one (two, five) of these insects (oriental cockroaches) in the kitchen, would you say this person has an insect problem?" The action residents had taken against cockroaches was determined by asking, "Have you taken steps to control these insects (oriental cockroaches)?" (If yes) "What have you done to control them?"

Respondents were then shown a live evaniid wasp and asked, "Have you seen this type of insect in your home during the past 6 months?" To determine the distribution of evaniid wasps, residents who had seen the wasps were asked, "In which rooms in your apartment have you seen them?" Seasonal abundance of wasps was evaluated by several questions: "Are there certain times of the year when you see these insects (evaniid wasps) more regularly or frequently than at other times?" (If yes) "When do you see them more frequently?" "During (peak season), how many of these insects do you find in your apartment in 1 week?" The two questions directly evaluating the pest status of evaniid wasps were "Do you consider them (evaniid wasps) to be a problem?" and "What about them bothers you the most?" The action residents had taken against the wasps was determined by asking, "What do you do with these insects (evaniid wasps) when you find them?" The immediate influence of information on modifying resident reactions toward evaniid wasps was assessed by the question: "When these insects (evaniid wasps) are growing up, they eat cockroach eggs. Each insect eats an average of 16 to 18 cockroach eggs. They do not sting. Knowing this information, what will you do when you find these insects in your home?"

2.1.3 Oriental Cockroach Trapping

Oriental cockroaches were trapped at two buildings, each with four apartments, at Lansdowne Park in the summer of 1984. Traps were modified 0.94 liter jars covered with stretch nylon (Granovsky 1983) and baited with 1/4 slice of beer-soaked bread. Indoors, three traps per apartment (12 traps per building) were placed at standardized locations: under the kitchen sink, on the kitchen pantry floor, and behind the upstairs toilet (Fig 1; upstairs traps are not shown). Traps were set out once a week and trap counts recorded 48 h later. There were 19 trapping occasions per building from May through mid-September. Outdoors, 16 traps were placed at standardized locations around the perimeter of each building (Fig. 1). Traps were set out once a week at dusk and final trap counts recorded ca. 3 h later (2300 hours-midnight). There were 14 trapping occasions per building from June through mid-September. The number of oriental cockroach nymphs and adult males and females caught in indoor and outdoor traps was recorded.

2.1.4 Evaniid Wasp Collection

Evaniid wasps were captured by residents of the two apartment buildings where oriental cockroaches were trapped. Resident cooperators in these eight households collected evaniid wasps with modified 44 ml vials and recorded the capture date and wasp location in the home. Separate records were maintained on the gender and collector of wasps and date received. Resident cooperators collected wasps from August 1983 through September 1984. Collaborators of three households collected 78% (43/55 wasps) of the total wasp catch in 1983, and 93% (76/82 wasps) of the total catch in 1984. The collection data from these three households were used to calculate the distribution and seasonal abundance of the wasps.

2.1.5 Data Analysis

The association between respondent demographic variables and their responses were tested using a X^2 test (SAS 1982a). Tests were considered significant at the 0.05 level.

2.2 RESULTS AND DISCUSSION

The duration of residency for respondents ranged from < 1 year to 33 years ($\overline{X} \pm SD = 11 \pm 9$). Respondents ranged in age from 16 to 88 years ($\overline{X} \pm SD = 49 \pm 19$). The majority (77%) of respondents were female.

2.2.1 Distribution and Abundance of Oriental Cockroaches

The majority of residents (90%) had seen oriental cockroaches around their apartment buildings. Significantly more Lansdowne Park residents (95%) compared with Lincoln Terrace residents (85%) had seen oriental cockroaches ($X^2 = 3.73$, df = 1, $P < 0.05$). Ninety percent of the residents who had seen oriental cockroaches found them indoors. More residents had seen cockroaches in the two rooms containing plumbing, the kitchen and upstairs bathroom, than in the other rooms (Table 1). Significantly more Lansdowne Park residents (57%) compared with Lincoln Terrace residents (33%) saw cockroaches in the bathroom (X^2 = 7.95, df = 1, $P < 0.005$). More residents had seen cockroaches on the front and back porches than in other outdoor areas (Table 1).

Resident perceptions of focal points of oriental cockroach activity corresonded well with cockroach trap counts. A total of 87 cockroaches (9 males, 43 females, 35 nymphs) was trapped indoors from May through mid-September 1984. Sixty-nine percent were trapped in bathrooms; the remaining 31% were trapped in kitchens. Mark-recapture studies have indicated that oriental cockroaches found indoors dispersed from haborages in exterior porches (section 3.2.2). Oriental cockroach movement indoors peaked during May and the first week of July (Fig. 2). A total of 1,789 cockroaches (356 males, 906 females, 527 nymphs) were trapped outdoors from June through mid-September 1984. Eighty percent of the cockroaches were trapped at porches. Porches were constructed of cinderblock faced with concrete. Cracks in the mortar facing provided cockroaches with access to insulated harborage spaces within the porches. Outdoor trapping data confirmed a seasonal shift in the age class structure of the cockroach population (Fig. 3) which has been reported by other researchers (Rau 1924, Gould and Deay 1940). The adult population peaked from mid- to late

June. From mid-July to September, the number of adult cockroaches declined while the number of nymphs increased, indicating that deposition of oothecae is seasonal (Ballard and Gold 1984).

2.2.2 Pest Status of Oriental Cockroaches

Eighty-two percent of the residents considered two oriental cockroaches indoors a problem, and 96% considered five cockroaches a problem (Table 2). In a survey conducted by Wood et al. (1981), RRHA residents were asked a similar question in reference to German cockroaches. Fifty-nine percent of the residents considered two German cockroaches a problem and 77% thought five were a problem. These results indicate that residents have a lower tolerance for oriental cockroaches compared to German cockroaches when found indoors. The residents' lower tolerance for oriental cockroaches may be due to the large size of the cockroach and perceptions of oriental cockroaches as indoor invaders from outdoor habitats.

The majority of residents (77%) had taken steps to control oriental cockroaches. Ninety-six percent of these residents used insecticidal control methods, including aerosol sprays (56% of the residents) and boric acid (23%). Two residents reported pouring bleach or gasoline into cracks of cockroach harborage sites in concrete porches. A higher percentage of residents who saw cockroaches indoors had used insecticides compared to residents who only saw the cockroaches outdoors (76% versus 21%, respectively). Only 7% of the residents used noninsecticidal control methods, including sanitation (5% of the residents), sticky traps (3%), or sealing cracks (1%). Resident reliance on insecticides to control cockroaches was also demonstrated in the survey by Wood et al. (1981). Fifty percent of the RRHA respondents considered insecticides the best method to control German cockroaches; only 12% of the residents thought integrating more than one control method was important.

2.2.3 Distribution and Seasonal Abundance of Evaniid Wasps

Sixty percent of the residents had seen evaniid wasps in their homes. Significantly more Lansdowne Park residents (71%) compared with Lincoln Terrace residents (49%) had seen evaniid wasps (X^2 = 7.44, df = 1, $P < 0.005$). Evaniid wasps were seen by residents in all rooms; at least 13% more residents had seen evaniid wasps in the kitchen compared with other rooms (Table 3). About 4% of the residents said they regularly found evaniid wasps in clothing and blankets stored in closets and dressers. Respondent perception of the indoor distribution of evaniid wasps was similar to the results of the wasp collection data in that wasps were collected in all rooms. Resident cooperators of three households collected a total 119 wasps (64 males, 55 females). A higher proportion of evaniid wasps (31%) was collected in the bathroom rather than in the kitchen (24%), living room (24%), or bedroom (21%). One resident cooperator collected live evaniid wasps between bed coverings on three occasions.

The majority of residents (86%) said there were certain times of the year when they saw evaniid wasps more frequently. Eighty percent of the residents regularly saw evaniid wasps in the summer, 10% saw wasps in the spring, 3% saw them in the fall, and 7% were uncertain. Respondent perceptions of evaniid wasp seasonality were supported by wasp collection data. The number of evaniid wasps captured by resident cooperators peaked three times: mid-May, mid-June, and late July to early August (Fig. 4). The population peaks occurred ca. 5 weeks apart, the minimum time recorded for evaniid wasps to complete their development from egg to adult at 27° C in the experiments described in section 5.2.2. The occurence of P. punctata corresponded with seasonal production of oothecae by oriental cockroaches. Cooperators did not find evaniid wasps in their homes from October 1983 through April 1984. P. punctata diapauses during the winter inside the cockroach eggcase (Edmunds 1952).

During the peak season, residents estimated that they saw a mean of 3.5 ± 4 evaniid wasps a week in their apartments. Estimates ranged from 1 to 30 wasps a week. Resident estimation of evaniid wasp abundance was consistent with wasp collection data. In 1984, one cooperator collected a total of 53 wasps over a 15-week period (65% of the total catch). The mean wasp catch for this cooperator, 3.5 wasps per week, was identical to the mean estimated by the survey respondents.

2.2.4 Pest Status of Evaniid Wasps

The majority of residents (70%) did not consider evaniid wasps to be a problem and 40% were not bothered by them. Significantly more Lincoln Terrace residents (76%) compared with Lansdowne Park residents (24%) were bothered by evaniid wasps ($X^2 = 6.06$, df = 1, $P < 0.01$). In addition, evaniid wasps bothered significantly more women (67%) than men (38%)($X^2 = 5.70$, df = 1, $P < 0.025$). About 28% of the residents were bothered by the wasps because they disliked insects in general. Only one-third of the residents (32%) were bothered by evaniid wasps for specific reasons. These reasons included fear of being bitten or stung (9% of the residents), dislike of the wasps flying around and "jumping" on them (6%), misidentification of the wasps as mosquitoes or spiders (4%), no idea what the wasp was (3%), and belief that wasps carried germs (4%) or looked "weird" (4%). At least three respondents complained of being bitten by evaniid wasps. Two resident cooperators said they were bitten by evaniid wasps and saved the wasps as evidence. The cooperators were bitten when the evaniid wasps were pinched between exposed skin and clothing or bedsheets.

The majority of residents (89%) killed the evaniid wasps they found. Wasps were killed by crushing (71% of the residents) or by insecticides (18%). Only 11% of the residents placed evaniid wasps outdoors or left them alone. Significantly more Lincoln Terrace residents (100%) compared with Lansdowne Park residents (81%) killed evaniid wasps ($X^2 = 7.70$, df = 1, $P < 0.01$). Evaniid wasps were killed by significantly more women (93%) than men (76%)($X^2 = 4.59$, df = 1, $P < 0.05$).

Providing residents with information on evaniid wasps dramatically modified their reactions toward these insects. After learning of the beneficial aspects of evaniid wasps, only 30% of the residents would have killed these insects and 70% would have saved the wasps. Significantly more Lincoln Terrace residents (51%) compared with Lansdowne Park residents (15%) would have killed the wasps (X^2 = 13.6, df = 1, P < 0.001). The reactions of women and men were not significantly different (X^2 = 1.57, df = 1, P > 0.10).

2.2.5 Conclusion

The survey and insect collection data defined the interactions between residents, oriental cockroaches, and evaniid wasps. The resident survey established that RRHA residents were intolerant of oriental cockroaches when found indoors. Trapping confirmed that the primary harborage sites were in exterior porches and foundation voids and not in resident living areas; only 5% of all oriental cockroaches trapped were caught indoors. These results indicate that a control program should be designed to identify and eliminate oriental cockroach entry routes indoors and to apply insecticides before the cockroach population peak in late June.

This research indicated that evaniid wasps should be considered as naturally occurring control agents in an integrated cockroach management program. The distribution and life cycle of the oriental cockroaches and evaniid wasps were closely synchronized. Another important consideration for the use of a biological control agent in an urban environment is acceptance of the agent by the target audience. Residents demonstrated the ability to tolerate the presence of evaniid wasps in their homes. Despite the similar resident demography of the two RRHA complexes, significantly fewer Lansdowne Park residents compared with Lincoln Terrace residents were bothered by evaniid wasps and would have killed these insects. Lansdowne Park was profiled as a more suitable location for integrating evaniid wasps into an oriental cockroach management program. Every target audience is defined by a unique combination of demographic variables; thus, tolerance levels need to be determined for each housing situation (Zungoli and Robinson 1985). To determine the success of evaniid wasps as biological control agents, three additional parameters need evaluation: 1) oviposition potential and field parasitism rates of evaniid wasps, 2) efficacy of education programs for increasing resident acceptance of wasps, and 3) effect of insecticide applications on wasp populations. Evaluation of the first and second parameters is presented in Chapter 5.

Resident perceptions of the distribution and seasonal abundance of evaniid wasps and oriental cockroaches concurred with field collection data. This research demonstrated that resident observations on household insect pests can assist the entomologist in locating harborage sites, defining activity periods, and revealing undocumented behavior of these insects. Entomologists should not assume that lack of formal education or training precludes residents from making accurate observations on insect activity in their homes.

Residents serve as both arbiter and resource for the urban entomologist. Their expectations for control and attitudes toward household insects can provide the ultimate determinant for success of a pest management program. Resident interactions with target insects can provide useful information on insect behavior and ecology. Thus, surveys evaluating resident knowledge and attitudes toward target insects should be considered an essential component of urban pest management programs.

TABLE 1

Resident sightings of oriental cockroaches, Roanoke, Va., 1984

Positive response	LP[1] (%)	LT[2] (%)	$\overline{X}$ (%)
Indoor locations			
Kitchen	82	72	77
Bathroom[3]	57	33	46
Living room	25	38	31
Bedroom(s)	14	6	10
Outdoor locations			
Front porch	51	58	54
Back porch	46	53	49
Sidewalks	15	25	20
On grass	10	16	13

[1] LP = Lansdowne Park

[2] LT = Lincoln Terrace

[3] Responses of residents at two complexes are significantly different ($P < 0.01$; X^2 test).

TABLE 2

Resident tolerance of oriental cockroaches found indoors, Roanoke, Va., 1984

Response	LP[1] (%)	LT[2] (%)	$\bar{X}$ (%)
One cockroach a problem			
Yes	58	63	60
No	32	28	30
Don't know	10	9	10
Two cockroaches a problem			
Yes	82	81	82
No	13	16	14
Don't know	6	3	4
Five cockroaches a problem			
Yes	96	97	96
No	3	2	2
Don't know	1	2	1

[1] LP = Lansdowne Park

[2] LT = Lincoln Terrace

TABLE 3

Resident sightings of evaniid wasps in apartments, Roanoke, Va., 1984

Positive response	LP[1] (%)	LT[2] (%)	$\bar{X}$ (%)
Kitchen	61	43	54
Living room	44	35	41
Bathroom	44	32	40
Bedroom(s)	41	27	35
Outdoors	2	27	12

[1] LP = Lansdowne Park

[2] LT = Lincoln Terrace

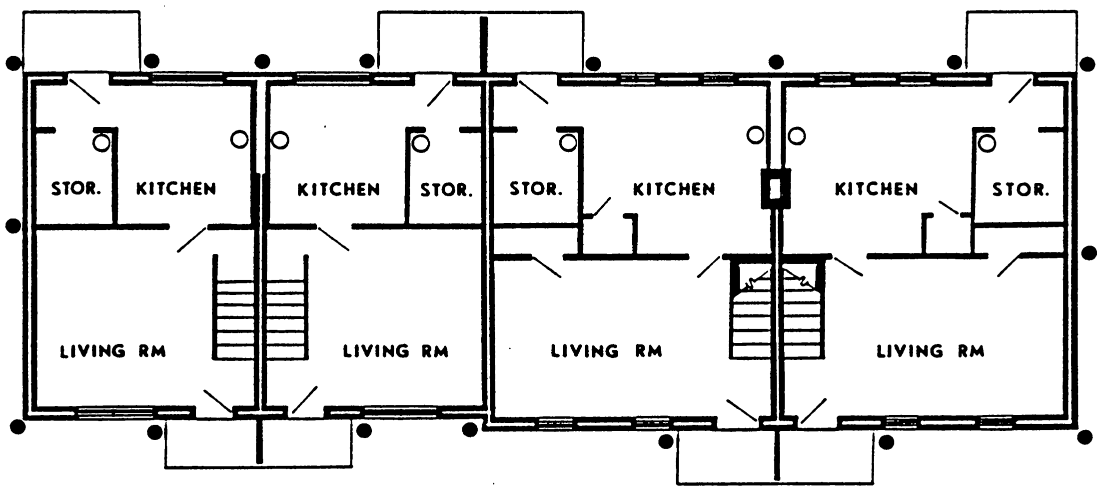


Figure 1: First-floor plan, dimensions 42.4 by 8.2 m, depicting placement of traps for oriental cockroaches

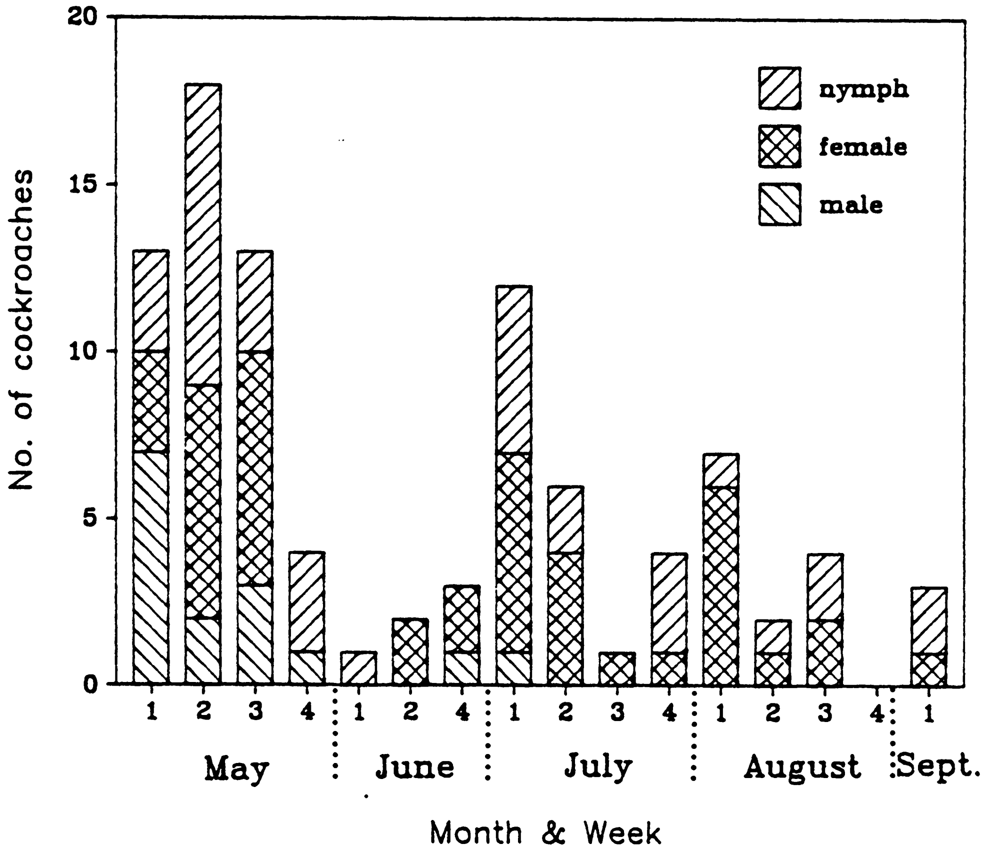


Figure 2: Oriental cockroaches trapped indoors, buildings 1 and 2, Roanoke, Va., summer 1984

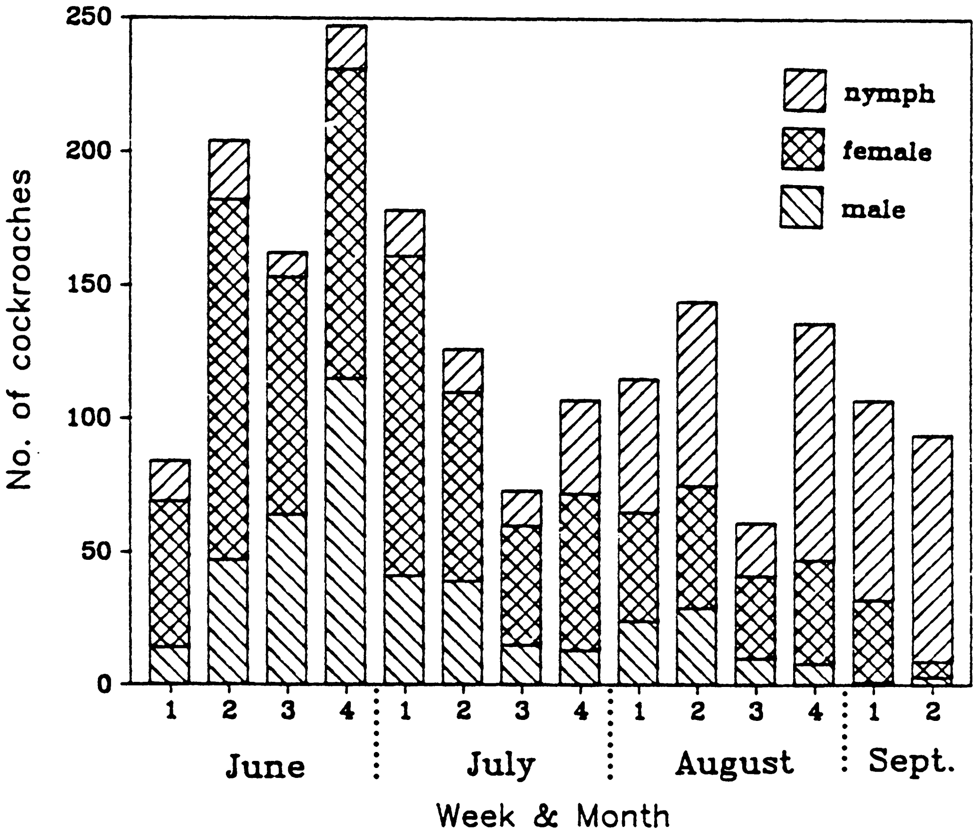


Figure 3: Oriental cockroaches trapped outdoors, buildings 1 and 2, Roanoke, Va., summer 1984

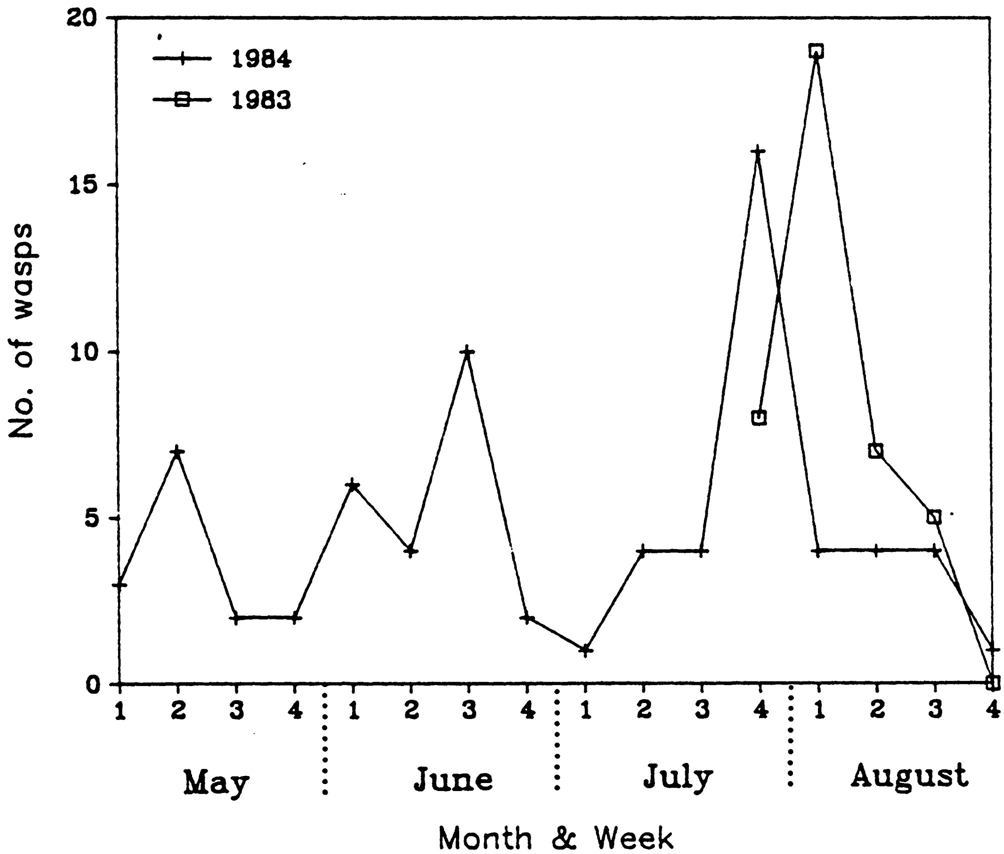


Figure 4: Total evaniid wasps caught indoors, three apartments, Roanoke, Va., 1983-84

Chapter III

DISTRIBUTION AND MOVEMENT OF ORIENTAL COCKROACHES

Understanding the normal movement patterns of oriental cockroaches is essential for deciding how to reduce or prevent their occurence indoors. The oriental cockroach generally finds harborage outside living areas in basements and crawlspaces (Ebeling 1978), trash chutes (Nixon 1984), wall and porch voids (section 2.2.1), refuse dumps (Gould 1940), and sewers (Anonymous 1957). Residents are intolerant of oriental cockroaches found indoors and perceive these large cockroaches as important domicilary pests when they move into structures from outside sources (section 2.2.2).

Carefully documented studies of movement of tagged individuals have been conducted for the smokybrown cockroach (Fleet and Frankie 1974, Fleet et al. 1978, Appel and Rust 1985), the German cockroach (Zungoli 1982, Runstrom and Bennett 1984), but not the oriental cockroach. Oriental cockroaches may have reduced movement capabilities compared to these species because they lack arolia and are flightless as adults (Ebeling 1978). However, reports of oriental cockroaches dispersing from refuse dumps and through sewers to nearby homes indicate these cockroaches may be capable of moving relatively long distances (Gould 1940, Pul'ver 1973). The purpose of the research presented here was to determine the distribution and movement of marked, field collected oriental cockroaches around and into apartment buildings.

3.1 MATERIALS AND METHODS

3.1.1 Study Site

Field work was conducted at four RRHA buildings in the Lansdowne Park complex. Each building contained four apartments, was constructed of concrete, cinderblock, and brick, and had a crawlspace with exposed soil. A 3 m wide concrete patio spanned the length behind each building. Buildings 1 and 2 were adjacent, separated by at least 6 m (Fig. 5). All apartments in these two buildings were two-story; the kitchen and living room were on the first floor and the bathroom and bedrooms were on the second floor. Buildings 3 and 4 faced each other, separated by 76 m of grass courtyard (Fig. 5). The two middle apartments of these buildings were two-story and the two end apartments were one-story. In all buildings, the kitchens and bathrooms of the two end pairs of apartments were serviced by common plumbing connections.

3.1.2 Composition, Seasonal Abundance, and Distribution

Oriental cockroaches were trapped indoors and outdoors at buildings 1 and 2 during the summers of 1984 and 1985. Traps used during 1984 were modified 0.94 liter jars baited with beer-soaked bread. The trapping procedure for 1984 was described in section 2.1.3 and was the same for 1985, with the following exceptions: unbaited Mr. Sticky® traps were used indoors instead of jar traps and ten 0.47 liter jar traps, two per porch, were placed around the perimeter of each building instead of 16 0.94 liter jar traps. Adult cockroaches trapped outdoors at buildings 1 and 2 in 1984 and building 1 in 1985 were tagged with plastic bee markers to assess cockroach movement (see section on movement).

Effect of jar size on trap-catch was assessed during three trapping periods in April and May, 1985. One 0.94 liter jar and one 0.47 liter jar were placed side-by-side at ten locations around buildings 1 and 2. The effect of temperature on trap-catch was assessed during the last week of June 1985, by trapping on seven successive days at building 1. Temperature and precipitation data were obtained from the National Weather Service at the Roanoke Regional Airport, ca. 8.0 km from the study site.

3.1.3 Cockroach Movement Outdoors

Cockroach movement around and between buildings was evaluated at all four buildings during the summer of 1984. Movement was assessed by trapping, marking, and releasing field-collected cockroaches, and then retrapping or resighting these marked cockroaches. Oriental cockroaches were trapped outdoors at buildings 3 and 4 using the same procedures described for buildings 1 and 2 (section 2.1.3). Adult cockroaches were individually tagged with plastic bee markers and returned to the exact location where they were trapped. Markers were colored red, green, blue, white, or yellow, numbered 0 to 99, and 2 mm in diameter (C.H.R. Graye, Wuttemberg, Germany). Markers were affixed to the cockroach pronotum using Duro® Superglue (Loctite Corp., Cleveland, Ohio). Laboratory tests indicated 5% marker loss and no significant mortality of cockroaches over a 6 month period using this marking technique. To check for marker loss in the field population, the right wing of each marked male was notched along the posterior edge. The presence of trapped, unmarked males with notched wings was recorded.

A grid with 2 m coordinates was marked within 4 m around the sides and back of each building (Fig. 6; dots are grid coordinates). The concrete patio extending along the back of each building facilitated observations of cockroach movement. Marked cockroaches were searched for on these grids and their locations were mapped. Approximately 50 grid surveys were conducted at each building from June 28 to September 23, 1984. Half of the surveys were conducted on nights when traps were not set out; the other half were conducted on trapping nights. Movement from buildings 3 and 4 to four adjacent duplex buildings (Fig. 5; duplexes marked with hatch lines) was assessed by trapping bimonthly at the duplexes from July 1 to September 12, 1984 as part of an evaluation of structural modification (section 4.1.3).

3.1.4 Cockroach Movement Indoors

Cockroach movement into resident living areas was evaluated at buildings 1 and 2 during the summer of 1984. Movement was assessed by retrapping marked cockroaches indoors (section 2.1.3) and by residents capturing marked cockroaches indoors. Residents of buildings 1 and 2 used modified 44 ml vials to collect marked cockroaches indoors and recorded the capture date and cockroach location.

3.1.5 Cockroach Movement in Crawlspaces

Cockroach movement in crawlspaces was evaluated at building 1 during the summer of 1985. Cockroaches were trapped and marked as described above. Movement was assessed by retrapping marked cockroaches in crawlspaces. Two Mr. Sticky traps were placed in 22 locations, 12 next to vents and 10 in corners, in the crawlspace. At each location, one sticky trap was attached vertically to the wall, adjacent to the ceiling, and the second trap was placed horizontally on the floor, adjacent to the wall. Traps were monitered once every two weeks from July 15 through September 15.

3.1.6 Data Analysis

The association between trap-catch and trap size or trap placement was measured using the Student's t test (SAS 1982a). The Pearson product-moment correlation test was used to measure the correlation between trap-catch and daily maximum or minimum temperatures (SAS

1982a). The association between type of movement and gender, resighting rate, or building was measured using a X^2 test (SAS 1982a). The model for categorizing type of movement is described below.

3.2 RESULTS AND DISCUSSION

3.2.1 Composition, Seasonal Abundance, and Distribution

The oriental cockroach was the predominant cockroach species captured in outdoor traps. American and German cockroaches were infrequently caught in outdoor traps. The German cockroach was the predominant cockroach species caught in traps indoors.

In 1985, a total of 1,269 cockroaches (251 males, 425 females, 593 nymphs) were trapped outdoors during from June through mid-September (Fig. 7). Results of the 1984 outdoor trapping were reported in section 2.2.1 to provide comparison with resident perceptions of cockroach infestations. Data from outdoor trapping at buildings 1 and 2 indicated similar trends in 1984 and 1985 for the seasonal abundance of adult cockroaches. In both years, the adult population peaked in mid-summer, during the fourth week of June in 1984 (Fig. 3) and the first week of July in 1985 (Fig. 7). The number of adults declined from mid-July through September in 1984 and 1985.

The proportion and seasonal abundance of nymphs were different in 1984 and 1985. Nymphs composed 30% of the total trap-catch in 1984, and their numbers in traps increased rapidly beginning the last week of July 1984 (Fig. 3). Nymphs composed 47% of the total trap-catch in

1985 and their numbers gradually increased beginning the third week of June 1985 (Fig. 7). The differences between years were apparently the result of trap biases. The 1985 comparison trapping test demonstrated that significantly more nymphs were trapped per 0.47 liter jar used in 1985 compared to 0.94 liter jar used in 1984, 2.0 versus 0.7, respectively (Student's t test on pooled data; $t = 2.00$, $P < 0.05$, df = 9). There was no significant difference between the two trap sizes in the number of adults caught.

Trap-catch for separate or pooled life stages and the daily maximum (27-34° C) and minimum (12-21° C) temperatures for the last week of June 1985 were not correlated ($P > 0.05$; Pearson product-moment correlation test). Appel and Rust (1985) reported no correlation between trap-catch of smokybrown cockroaches and temperature during a two week period in June. In contrast, Fleet et al. (1978) reported a correlation between trap-catch of smokybrown cockroaches and maximum temperatures during a 16 month trapping period. However, this may have indicated seasonal abundance of a cockroach population rather than temperature dependent activity of individual cockroaches. Adult populations of smokybrown cockroaches were highest in June during warm weather and lowest in February during cold weather (Fleet et al. 1978).

The total number of oriental cockroaches trapped daily in 1984 and 1985 appeared to be reduced if measurable (0.05-1.3 cm) rainfall occurred on the trap day (Fig. 8; arrows indicate rainfall). Correlating trap-catch with rainfall was not possible because rainfall was infrequent and the seasonal decline of adults also reduced the trap-catch (Fig. 7). Appel and Rust (1985) reported the trap-catch of smokybrown cockroaches was significantly lower on rainy days than on clear days.

In 1985, a total of 157 cockroaches (56 males, 72 females, 29 nymphs) were trapped indoors from May 6 through September 9 (Fig. 9). Results of the 1984 indoor trapping were reported in section 2.2.1 to provide comparison with resident perceptions of cockroach infestations. Data from indoor trapping at buildings 1 and 2 did not indicate similar trends in 1984 and 1985 for the seasonal abundance and distribution of oriental cockroaches. Oriental cockroach movement indoors peaked twice in 1984 during the second week of May and the first week of July (Fig. 2) and once in 1985 during the second week of June (Fig. 9). Approximately equal numbers of cockroaches were trapped in bathrooms during both years; 60 in 1984 and 51 in 1985. Four times more cockroaches were trapped in kitchens in 1985 (106) compared to 1984 (27). More oriental cockroaches may have been trapped indoors in 1985 than in 1984 because sticky traps were used. Oriental cockroaches are trapped more readily in sticky traps than other cockroach species (Moore and Granovsky 1983).

3.2.2 Cockroach Movement Outdoors

A total of 1,177 adult oriental cockroaches were trapped and marked at four buildings during the summer of 1984 (Table 4). The male:female ratio of trapped adults was 1:2.2. Observations of oriental cockroaches around RRHA buildings suggest the actual sex ratio may have been closer 1:1. Mark-recapture studies of the smokybrown cockroach (Fleet et al. 1978, Appel and Rust 1985) have also indicated a 1:1 sex ratio. The food bait in traps may have been more attractive to adult females than to adult males. Oriental cockroach females and nymphs were regularly observed feeding on a variety of organic matter: garbage; dead insects, slugs, and vertebrates; turf grass; and bird droppings. Males were infrequently observed feeding. Seelinger (1984) observed females and nymphs of the American cockroach and the Australian cockroach, *Periplaneta australasiae* (Fabr.) feeding on fallen flowers, but rarely saw males feed.

Forty-one percent of the oriental cockroaches marked were later resighted, i.e. captured in traps, collected by residents, or seen during a grid survey (Table 4). Eight males with notched wings but no markers were resighted, indicating a marker loss rate of 7%. The number of times resighted cockroaches were observed averaged 2.3 (Table 4) with a maximum of 19 resightings for one female cockroach. Adult longevity, limited movement, and frequent observation periods were probably responsible for the high resighting rate. Marked cockroaches were relatively long-lived; the sum of days between the first and last observations for each cockroach averaged 24 days (Table 4) with a maximum of 107 days. Oriental cockroaches demonstrated limited dispersal within the study site; less than 2% of the resighted cockroaches moved between buildings. There were 66 trapping and observation periods for this study. High recapture/resighting rates of 40-62% have also been reported for Periplaneta species in marking studies with a minimum of 24 trapping and observation periods (Fleet et al. 1978, Seelinger 1984).

The percentage of resighted oriental cockroaches and the number of times these cockroaches were resighted were significantly dependent on building site (percent resighted: $X^2 = 71.97$, df = 3, $P < 0.001$; times resighted: $X^2 = 57.14$, df = 9, $P < 0.001$) (Table 4). Significantly more females than males were resighted, 46% versus 31%, respectively ($X^2 = 23.61$, df = 1, $P < 0.001$); however, the number of times these females or males were resighted were not significantly different ($X^2 = 1.43$, df = 3, $P > 0.50$). In mark-recapture studies, a statistically greater proportion of female smokybrown cockroaches were resighted significantly more often than males (Fleet et al. 1978, Appel and Rust 1985).

Cockroach movement data have previously interpreted from two different perspectives. One perspective was to analyze cockroach movement in terms of distance between resightings. The mean distance moved between successive captures was used as the radius of a circle representing the home range of the smokybrown cockroach (Fleet et al.

1978, Appel and Rust 1985). Recaptive radii methods assume an animal's home range is symmetrical and its movement within this area is random and normally distributed (Rose 1982). This assumption does not accurately describe cockroach home ranges within the asymmetrical, heterogeneous surroundings of man's dwellings. The recaptive radius method overestimated the home range of the smokybrown cockroach, calculated to be 108 - 300 m^2 (Fleet et al. 1978, Appel and Rust 1985) if the assumption of symmetrical home range was inaccurate.

Another perspective to studying cockroach movement was to analyze movement in relation to structural features. Movement of German cockroaches between rooms and apartments was categorized according to the proximity of rooms and apartments and the presence or absence of common plumbing connections (Akers and Robinson 1981, Zungoli 1982, Runstrom and Bennett 1984). This method effectively demonstrated the influence of environmental features on cockroach movement, but provided no estimates of actual distance moved.

Both perspectives were integrated in this study by estimating cockroach range of movement in relation to structural features. The greatest distance between any two out of all resightings, called the maximum distance, was calculated for each cockroach. Maximum distances for cockroaches observed on different sides of a building were determined by assuming cockroaches moved from one location to the next by following the foundation perimeter (Fig. 6 ; cockroach A). Maximum distances for cockroaches observed outdoors and indoors were determined by assuming cockroaches moved indoors under door thresholds or along plumbing connections, discussed below in movement indoors.

Cockroach movement was divided into four categories based on dispersal from porches, the primary harborage sites of oriental cockroaches at RRHA buildings. Eighty percent of all oriental cockroaches trapped at buildings 1 and 2 in 1984 were caught next to porches (section 2.2.1). Buildings were subdivided into separate zones (Fig. 6; shaded regions delineate zones), each representing the activity area for cockroaches originating from a porch centrally located within the zone. Movement was categorized according to cockroach movement within and between zones. Type I movement was contained within one zone (Fig. 6; cockroach A). Type II and III movement occurred between two zones and three to four zones, respectively, on the same side of a building. Type IV movement occurred between zones on opposite sides of a building (Fig. 6; cockroach B), and included movement between buildings.

The majority of oriental cockroaches marked in 1984 demonstrated limited movement. The maximum distance moved by resighted cockroaches averaged 8.4 ± 8.9 m with 50 m being the longest distance moved. Similar maximum distances were obtained for males and females and for cockroaches at different sites. Maximum distances varied significantly between Types I to IV movement categories ($F = 405.7$, $df = 3$, $P < 0.001$) (Table 5). Fifty percent of the resighted cockroaches moved a mean maximum distance of 2 m and remained within the activity zone of one porch. Twenty-four percent of the resighted cockroaches moved a mean maximum distance of 9 m, moving between the zones of two adjacent porches on the same side of a building. Although 26% of the resighted cockroaches moved a mean maximum distance of 20 m in the Type III and IV categories, less than 2% of the resighted cockroaches moved between adjacent buildings separated by only 6-10 m. Six marked cockroaches moved between buildings 1 and 2, and two cockroaches moved from building 4 to the duplex on the south side (Fig. 5).

Type of cockroach movement was significantly related to the number of resightings per cockroach (X^2 = 76.53, df = 9, $P < 0.001$) and building (X^2 = 32.99, df = 9, $P < 0.001$). The estimated movement changed from Type I to Type II or III as the number of resightings increased. Sixty-four percent of the cockroaches resighted one time exhibited Type I movement, whereas 68% of the cockroaches resighted five or more times exhibited Type II or III movement (Table 5). The oriental cockroach is not territorial and may wander widely in search of resources (see below). Home range estimates for other nonterritorial, actively foraging animals increase continously as the number of sightings increase (Rose 1982). The relationship between estimated movement and number of resightings has not been addressed in previous research on cockroach dispersal (Fleet et al. 1978, Runstrom and Bennett 1984, Appel and Rust 1985).

The differences between buildings in cockroach movement was due in part to the difference in positions of cockroach-infested porches at each building. Twice as many of cockroaches were trapped near the two porches at the back corners of building 1 (54% of the total) compared to the same locations at building 2 (23%). Cockroach movement at building 1 reflected dispersal along the back of the building between these porches (Type III movement) and to the front porches (Type IV movement)(Fig. 6). Twice the proportion of cockroaches at building 1 (34%) exhibited Type III and IV movement compared to those at building 2 (17%) (Table 5).

The differences between buildings in cockroach movement may also be due to the differences in the number of times cockroaches were resighted at each building. Cockroach resightings were significantly dependent on building ($X^2 = 57.14$, df = 9, $P < 0.001$). Thirty-three percent more cockroaches at building 2 compared to those at building 3 were resighted one time. Similarly, 15% more of the cockroaches at building 2 compared to those at building 3 remained in the area of one porch, Type I movement (Table 5).

Type of cockroach movement was not significantly dependent on gender in this study ($X^2 = 4.17$, df = 3, $P > 0.10$). Researchers have obtained different comparisons between movement of male and female blattid species. Fleet et al. (1978) reported no significant difference in the size of the home ranges of male and female smokybrown cockroaches, whereas Appel and Rust (1985) reported the home ranges of male smokybrown cockroaches were significantly greater than those of females. Researchers have obtained similar comparisons between movement of male and female blattellids. Silverman (1986) and Ballard et al. (1984) demonstrated that male German cockroaches were more active and explored farther distances than females. The difference between blattid and blattellid cockroaches in movement of females may be due to differences their reproductive physiology. Female German cockroaches carry the ootheca for nearly the entire incubation period of ca. four weeks (Cornwell 1968). Gravid females forage less frequently than males and nongravid females (Silverman 1986). In contrast, female Blatta and Periplaneta species carry the ootheca for only one or two days before depositing it (Cornwell 1968). Gravid female oriental cockroaches were observed moving distances of 25 m within two hours. No female oriental cockroaches bearing oothecae were caught in baited traps during 1984 or 1985, indicating that gravid females observed moving long distances may have been searching for suitable oviposition sites rather than food.

3.2.3 Cockroach Movement Indoors

Low percentages of marked cockroaches were captured indoors during the summer of 1984 at building 1 (5%, N = 21) and building 2 (1%, N = 4). All 25 marked cockroaches caught indoors were female. The number of marked oriental cockroaches moving indoors from a zone was approximately proportional to the infestation level of that zone.

Forty percent of all cockroaches marked at building 1 were caught at one porch; 48% (10) of the marked cockroaches found indoors were last sighted at this porch, shaded in Fig. 10 (upstairs bedrooms and bathrooms are not depicted). Eighty percent of all marked cockroaches found indoors moved to zones different from those they were last sighted in outdoors. The ten cockroaches last observed outdoors in the shaded area (Fig. 10) moved indoors to four zones in six rooms of three apartments. The locations where residents found marked cockroaches indoors indicated that major entry routes were under door thresholds into kitchens and living rooms and along plumbing into kitchens and bathrooms.

3.2.4 Cockroach Movement in Crawlspaces

A total of 99 cockroaches (33 males, 22 females, 44 nymphs) were trapped in the crawlspace of building 1 from July 15 through September 15 1985 (Fig. 11; V = vent, C = corner). Six (4 males, 2 females) out of the 242 cockroaches marked outdoors were trapped in the crawlspace. The previous outdoor trapping locations for these cockroaches indicated that only two marked cockroaches moved distances exceeding 5 m in the crawlspace.

Trapping data indicated that cockroach movement in the crawlspace was minimal from July through mid-August with cockroaches remaining on foundation walls near vents. Significantly more cockroaches were caught in wall traps (30) than in ground traps (0) from July 15 through August 15 (Student's t test; $t = 4.57$, $P < 0.001$, $df = 21$). A greater proportion of cockroaches were caught in vent traps (74%) compared to corner traps (26%) from July 15 through August.

Trapping data indicated that the increased cockroach movement into the crawlspace in late August and September was due to an influx of nymphs (Fig. 11). Ninety-three percent of the nymphs trapped in the crawlspace were captured from August 30 through September 15. During this time, significantly more cockroaches were caught in ground traps (53) compared to wall traps (16) (Student's t test; $t = 3.26$, $P < 0.005$, $df = 21$). Fifty-seven percent of the cockroaches caught during the last trapping interval were trapped in corners. The movement of cockroach nymphs in September onto the ground of the crawlspace and away from vents may indicate that these cockroaches were searching for overwintering sites. Notching the abdominal tergites of oriental cockroach nymphs at buildings 1 and 2 in September and October of 1984 and 1985 and recapturing notched adults each following May suggested that oriental cockroaches overwinter as mid- to large size nymphs. The absence of oriental cockroach activity outdoors and indoors at buildings 1 and 2 from December through March of 1984 and 1985 indicated that cockroaches overwintered in crawlspaces and voids of porches and walls.

3.2.5 Conclusion

Oriental cockroaches tend to remain near preferred harborage sites. The majority (85%) of the resighted cockroaches remained within zones on one side of a building (Table 5). Only 2% of the resighted cockroaches moved between buildings. The lack of movement between buildings may have been due to the absence of structural features and pheromone trails for oriental cockroaches to follow. Previous research has suggested that oriental cockroaches may return to their harborage sites by orienting to learned physical cues and chemical cues (Kanzler 1972, Bell et al. 1972, Bell et al. 1973). Oriental cockroaches demonstrated greater ability than blattellid cockroaches in learning how to move through mazes (Kanzler 1972). In addition, Oriental cockroaches secrete an aggregation pheromone in their feces (Bell et al. 1972); the orientation of another blattid species, the American cockroach, is directed by a feces-secreted aggregation pheromone (Bell et al. 1973).

The results of this investigation indicated when and where treatments would be most effective for managing oriental cockroach populations. Treatments should be applied in May or June, prior to the adult population peak in late June and July. Cockroaches aggregated around porches, the primary harborage sites, and vents in crawlspaces. Therefore, insecticides should be applied to the exterior foundation perimeter and porches, and to crawlspace or basement walls around vents or windows. Locations where marked oriental cockroaches were found indoors at building 1 indicated that entry routes were under doors and through wall openings around plumbing. Sealing gaps in walls where pipes enter into rooms and installing tightly fitting weather stripping around doors may help limit oriental cockroach movement indoors.

This study and other investigations (Fleet et al. 1978, Appel and Rust 1985) have indicated that the movement capabilities of oriental and smokybrown cockroaches may be different. However, these investigations used different methods for recording and analyzing cockroach movement. Each of the methods used had limitations which could have biased the interpretation of data if not recognized by the researchers. For example, low resighting rates per cockroach would tend to underestimate movement capabilities (Table 5), whereas using circular radii methods would tend to overestimate movement capabilities (Rose 1982). Separating the variation in cockroach movement which is species dependent from that which is experimentally dependent is very difficult.

TABLE 4

Mark-recapture data for adult oriental cockroaches, 4 buildings, Rcanoke, Va., Summer 1984

				$\overline{X}$ ± S.D.	
	Total Marked	Resighted %	N	Frequency[1] of resighting	Total[2] Days
Total:	1177	41	483	2.3 ± 2.0	24 ± 18
Building:					
1	399	46	183	2.4 ± 2.0	28 ± 21
2	466	30	141	1.7 ± 1.2	23 ± 15
3	121	60	73	3.8 ± 3.1	25 ± 18
4	191	45	86	1.8 ± 1.3	16 ± 9
Gender:					
Male	368	31	113	2.1 ± 1.9	20 ± 15
Female	809	46	370	2.3 ± 2.1	25 ± 19

[1] Number of times a single adult was recaptured and resighted.

[2] Sum of days between the first and last observations for each cockroach.

TABLE 5

Relationship of cockroach movement to study site and times resighted, 4 buildings, Roanoke, Va., Summer 1984

	N	1 Zone (I)	2 Zones on 1 sd. of building (II)	3-4 Zones on 1 sd. of building (III)	Zones on opp. sd. of building[1] (IV)
		Maximum distance (m)[2]			
	483	1.8 a	9.3 b	19.9 c	20.0 c
		Percent of cockroaches			
Total:	483	50	24	11	15
Times Resighted:					
1	246	64	16	6	14
2	98	46	32	9	13
3-4	79	32	30	16	22
5+	60	20	35	33	12
Building:					
1	183	47	19	12	22
2	141	57	26	4	13
3	73	42	30	21	7
4	86	49	27	16	8

[1] Includes movement between buildings.

[2] Values on a line followed by the same letter are not significantly different at $P < 0.05$ (Duncan's [1955] multiple range test).

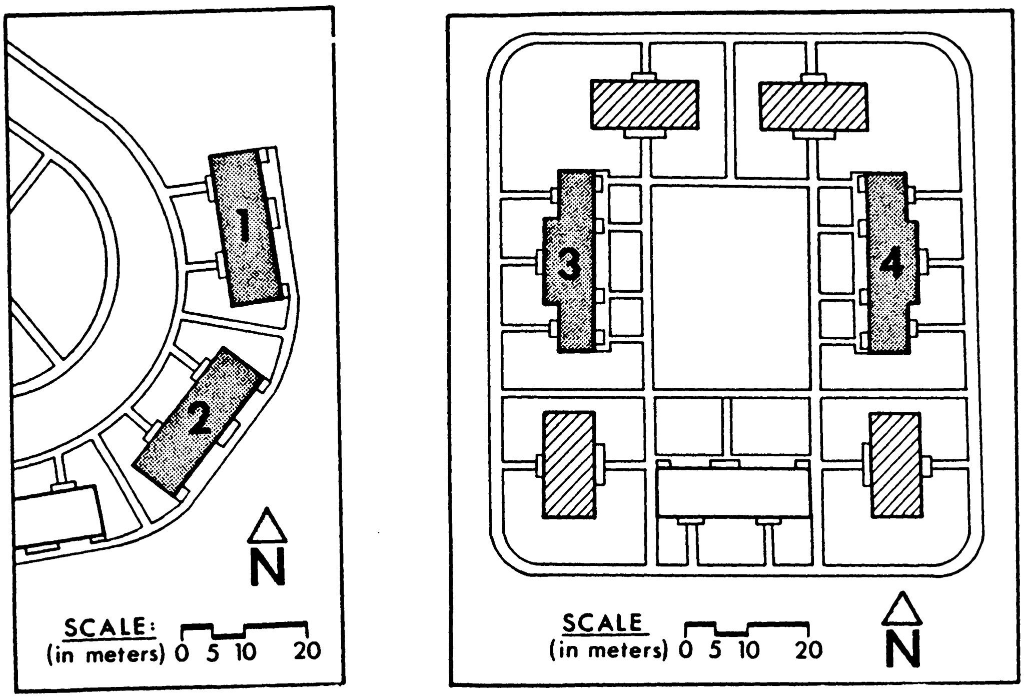


Figure 5: Buildings 1-4, field sites for oriental cockroach research, Roanoke, Va., Summer 1984 & 1985; duplex buildings used in structural modification study are indicated with hatch lines

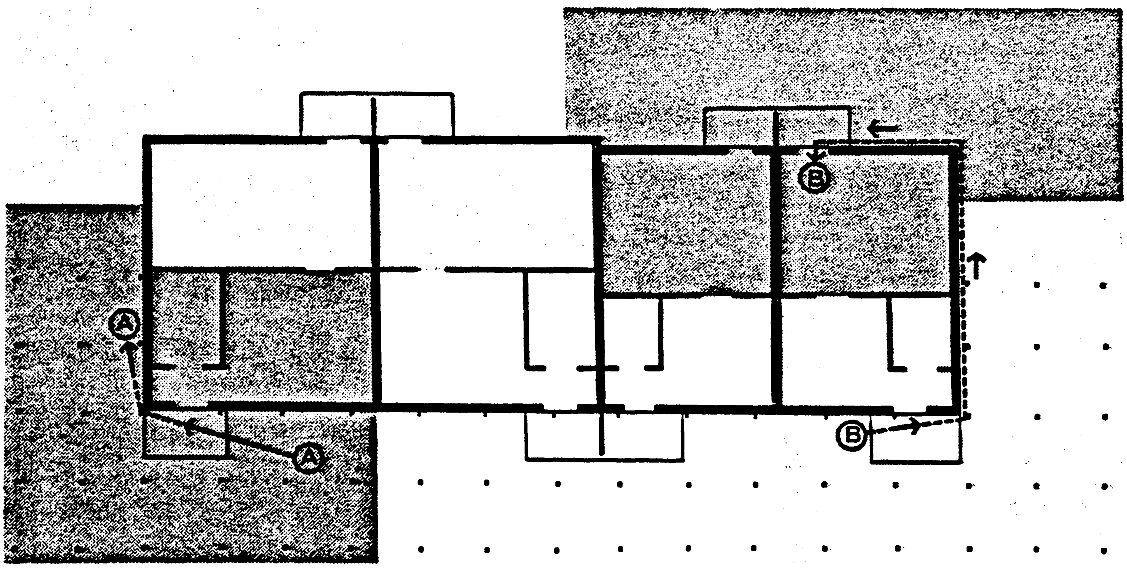


Figure 6: Model for calculating oriental cockroach movement around buildings 1 and 2, Roanoke, Va.; dots are grid coordinates, shaded regions delineate zones

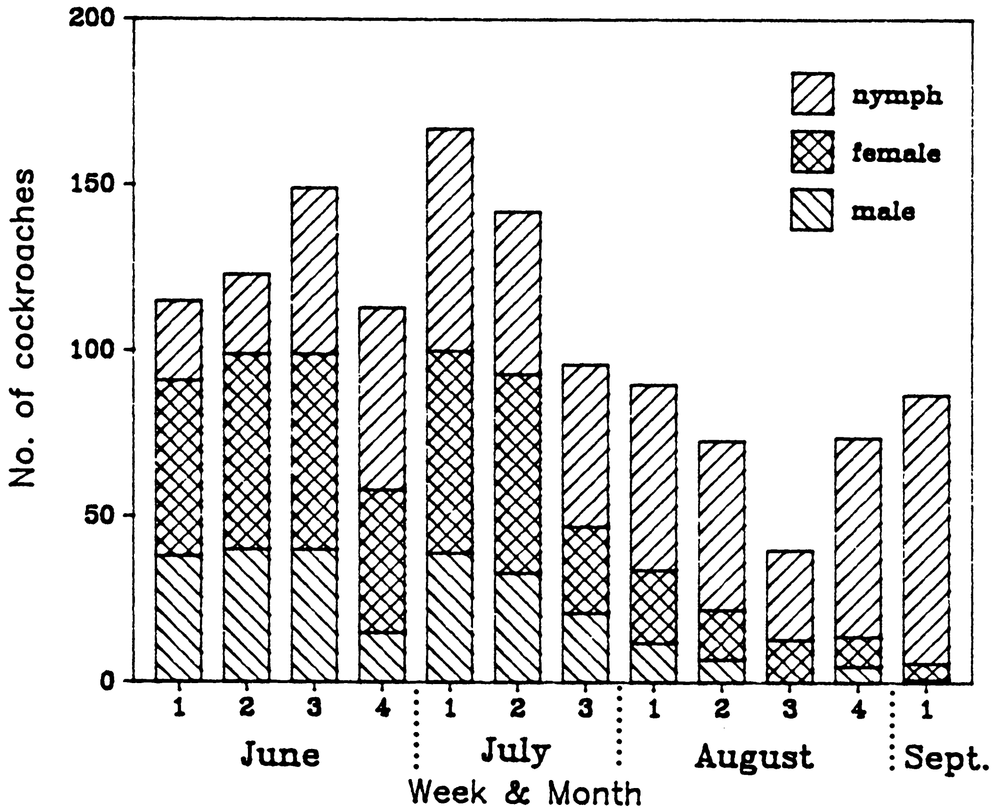


Figure 7: Oriental cockroaches trapped outdoors, buildings 1 and 2, Roanoke, Va., Summer 1985

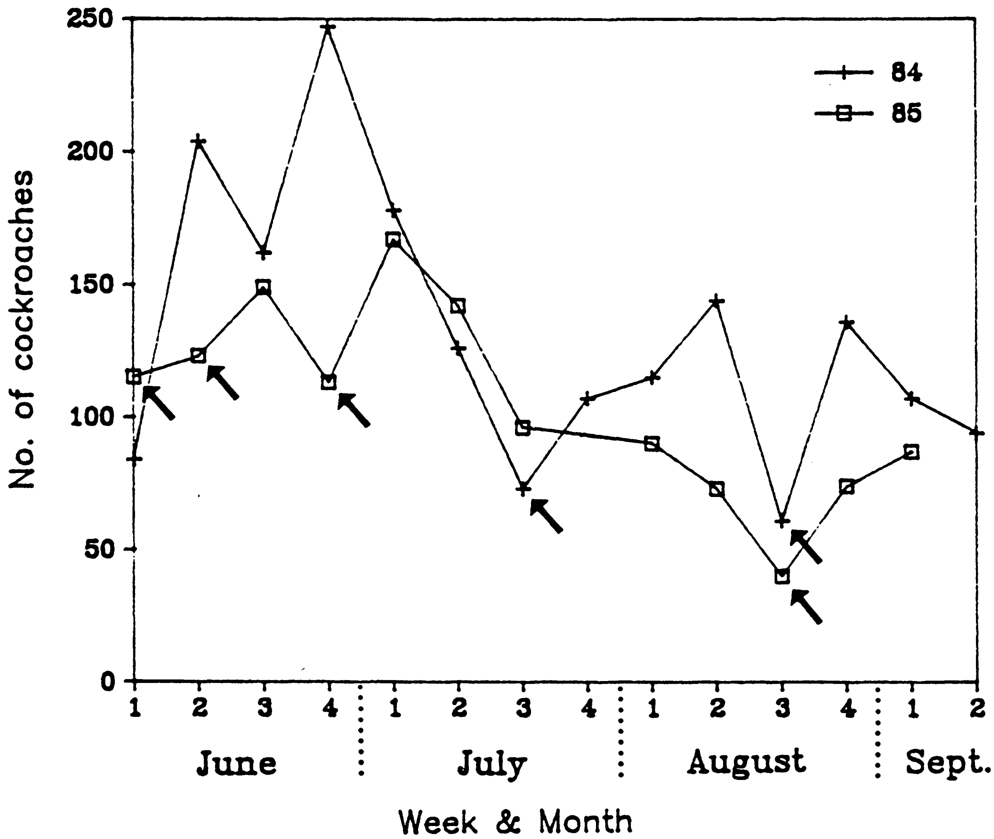


Figure 8: Total oriental cockroaches trapped outdoors, buildings 1 and 2, Roanoke, Va., Summer 1984 & 1985; arrows indicate trapping dates on which rainfall occurred

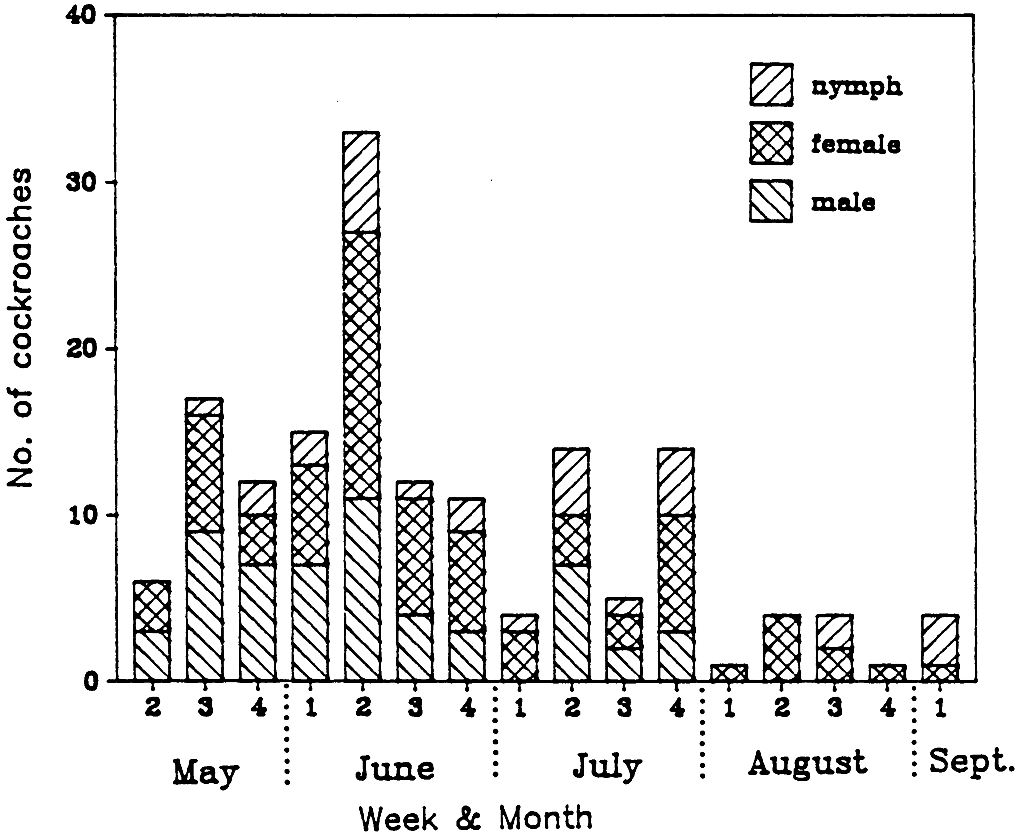


Figure 9: Oriental cockroaches trapped indoors, buildings 1 and 2, Roanoke, Va., Summer 1985

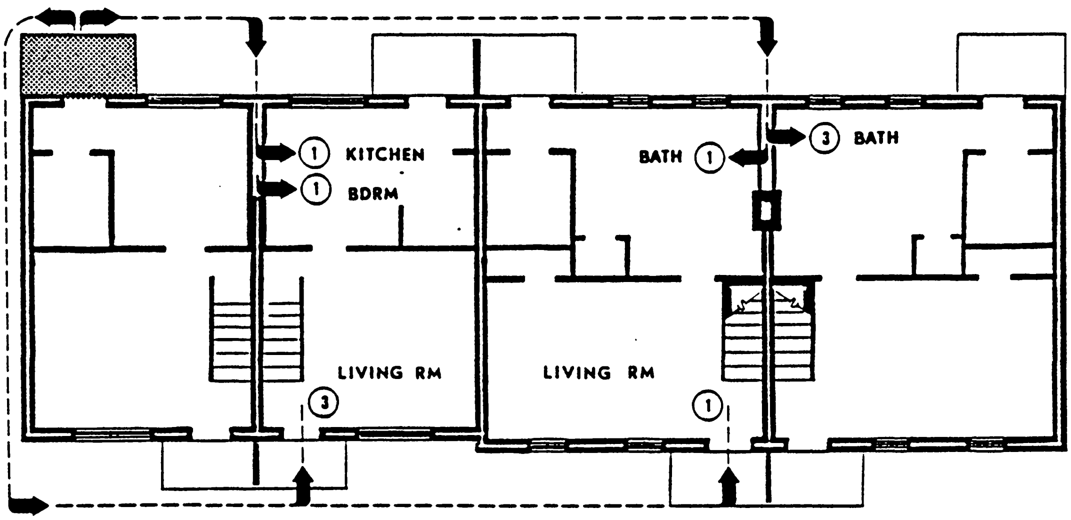


Figure 10: Oriental cockroaches, last observed outdoors at shaded porch, found indoors, building 1, Roanoke, Va., Summer 1985; ① ③ = Number of cockroaches found in each room

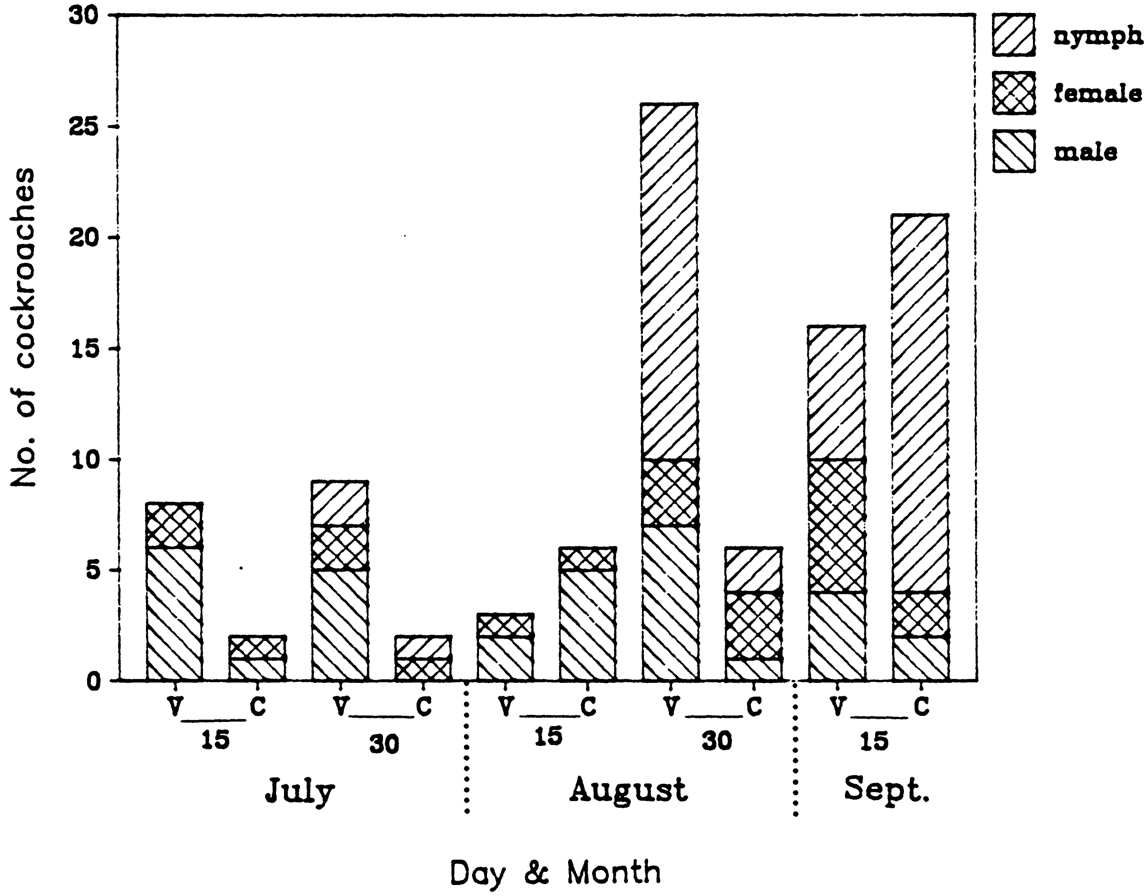


Figure 11: Oriental cockroaches trapped in the crawlspace, building 1, Roanoke, Va., Summer 1985; V = vent trap, C = corner trap

Chapter IV

INSECTICIDE FORMULATIONS AND STRUCTURAL MODIFICATION FOR THE MANAGEMENT OF ORIENTAL COCKROACH POPULATIONS

The spatial and temporal distribution of oriental cockroaches infesting apartment buildings was described in chapters 2 and 3. The results of this research indicated where and when insecticidal and non-insecticidal strategies would be most effective for reducing oriental cockroach populations. Porch and wall voids were the primary harborage sites of oriental cockroaches (section 2.2.1). Cracks and crevices in the concrete facing of porches and foundations provided access for cockroaches into the cinderblock voids. From these harborages cockroaches apparently moved through openings around doors and plumbing to enter apartments (section 3.2.2). Ideally, treatment of harborages should be conducted prior to the adult population peak in late June.

The objectives of the research presented here were to evaluate insecticide formulations and structural modification as methods for managing oriental cockroach populations. Evaluations were based on two criteria: percentage reduction of cockroach populations in field tests, and cost to treat 200 apartments in a 50 building complex.

4.1 MATERIALS AND METHODS

4.1.1 Study site

Apartment buildings used in this study were located in the RRHA complex of Lansdowne Park. Buildings were either one-story with two apartments or two-story with four or six apartments. Building structure was described in section 3.1.1. Some buildings were built with a partial basement. During pretreatment sampling, at least three oriental cockroaches were caught per trap per night outdoors at all buildings used in this study.

4.1.2 Insecticide formulations

Four insecticide formulations were evaluated: 0.5% Dursban® XRM 4808, microencapsulated chlorpyrifos similar to Dursban® ME (Dow Chemical U.S.A.); 1.0% KnoxOut® 2 FM, microencapsulated diazinon (Pennwalt Corp.); 0.5% Dursban® 4E, chlorpyrifos emulsifiable concentrate (Dow Chemical U.S.A.); and Combat®, hydramethylnon bait enclosed in 56 cm^2 plastic trays (American Cyanamid Co.). A replicate consisted of one apartment building. There were three replicates for each insecticide treatment and two untreated control replicates.

Treatments were applied on June 5, 1985. Liquid insecticides were applied using a compressed air sprayer with a coarse fan spray. Areas treated included exterior foundation surfaces, weepholes, crawlspace vents, porches, patios, sidewalk edges, and interior foundation surfaces in crawlspaces and basements. For Combat treatments, 20 bait trays were placed on horizontal surfaces at each building; 10 trays indoors in crawlspace vents and 10 trays outdoors at porches. Bait trays were secured to the outdoor substrate using 20 cm gutter spikes or silicon sealant on concrete patios.

Residents consider oriental cockroaches important pests when found found indoors (section 2.2.2). The number of marked cockroaches found indoors was proportional to the outdoor infestation levels (section 3.2.2). A reduction in the outdoor cockroach population would presumably reduce the number of oriental cockroaches moving indoors. Therefore, the oriental cockroach population was sampled outdoors at one wk pretreatment and 2, 4, 6, 8, and 12 wks posttreatment. Traps were modified 0.94 liter jars baited with beer-soaked bread (section 2.1.3). At dusk two traps were placed at each porch, 10 to 14 traps per building, and the number of oriental cockroach nymphs, and adult males and females were recorded about 3 h later (2300 - midnight).

After 12 wks, bait trays were returned to the laboratory. Bait was removed, placed in individual 29.6 ml plastic cups, lyophilized in a Vitronics model 51-TC freeze-dryer for 48 hours, then weighed on a Fisher/Ainsworth model LC-5500 digital scale. The dry weight of field baits was compared to the mean dry weight of five baits maintained in laboratory conditions.

4.1.3 Structural Modification

On July 8, 1984, from 2130 to 2230, the exterior of four duplex buildings were inspected and cockroach harborage sites in foundations, porches, and patios of each building recorded (Fig. 5; duplexes are marked with hatched lines). Prior to structural modification on July 22, three of the four duplex buildings were treated with 0.5% Dursban 4E using the same procedure described above, except interior foundation surfaces in the crawlspaces were not treated. Insecticides were applied to reduce the oriental cockroach infestation and to avoid forcing large numbers of live cockroaches, trapped in wall voids, to disperse into apartments. One building was left untreated.

Within one week after the application of Dursban 4E, two of the three treated buildings were structurally modified to limit access of oriental cockroaches into the foundation and crawlspace. Work was completed by RRHA maintenance personnel. Crawlspace vents were screened and sealed using silicon sealant. Cracks and spaces where pipes, electrical conduits, and porches separated from the foundation were also filled with silicon sealant. Deteriorated concrete facing of porches and foundations was repaired with mortar. Weepholes were plugged with nylon wicking and covered by a thin layer of mortar to permit movement of moisture but not cockroaches from the wall voids.

Sampling of the oriental cockroach population was the same as described above, with the following exceptions. Outdoor trap counts were taken one wk pretreatment and 2, 4, 8, and 52 wks posttreatment using baited jar traps. Indoor trap counts were taken weekly from May 20 to September 9, 1985, using unbaited Mr. Sticky traps. Three sticky traps were used per apartment; one beneath the kitchen sink, one under the refrigerator, and one behind the bathroom toilet.

4.1.4 Data Analysis

Mean percent reduction per treatment, transformed to arcsine $\sqrt{\%}$, and mean number of cockroaches per treatment were separated at $P < 0.05$ using Duncan's (1955) multiple range test (SAS 1982).

4.1.5 Cost Evaluation

Cost of materials and number of man-hours required to treat each building were recorded. A budget was calculated for each insecticide formulation and structural modification based on treatment of a hypothetical complex of 200 apartments. This complex would consist of 50 four-apartment buildings of the same construction described for Lansdowne Park. All buildings would be infested with oriental cockroaches. Placement of Combat bait trays and repairs for structural modification would be conducted by apartment maintenance personnel. Application of professional-use insecticides would be conducted by maintenance personnel certified for pest control or would be contracted to a pest control company.

4.2 RESULTS AND DISCUSSION

4.2.1 Percentage Reduction: Insecticide Formulations

In the pretreatment trap counts, the mean number of cockroaches trapped for each treatment were not significantly different (Table 6). The number of cockroaches trapped at the two control buildings was representative of the seasonal fluctuation in oriental cockroach populations (sections 2.2.1 and 3.2.1). The number of cockroaches per trap at the untreated control buildings increased by 47% at the four wk evaluation in early July, and decreased 31.5% by the 12 wk evaluation in August. At 12 wks posttreatment, the reduction in cockroaches in the insecticide treatments was probably the result in part of a natural seasonal decline rather than residual insecticide activity. Insecticidal control was more reliably represented by the initial eight wks posttreatment. Throughout this period, all insecticide treatments resulted in significantly ($P < 0.01$) greater reduction in cockroaches compared to the control. The two encapsulated formulations, Dursban and KnoxOut, gave the greatest percentage reduction, at least 94% and 85%, respectively, throughout eight wks. Cockroach reduction with the Combat bait trays gradually diminished to a low of 50% reduction by eight wks. Apparently an insufficient number of bait trays were placed at each building, because bait was emptied from trays before cockroach populations had been controlled. By the 12 wk evaluation, replicate 2 had no reduction in cockroaches and no bait remained in outdoor trays (Table 7). Excluding this replicate, oriental cockroaches were reduced by 76% at eight wks posttreatment at the two buildings where bait remained in outdoor trays. Weight of bait remaining in each tray at 12 wks posttreatment was not correlated (Pearson product-moment correlation; $r = -0.150$) to the number of cockroaches trapped adjacent to the tray before treatment. Other insects, particularly ants, may have removed bait from Combat stations. Only encapsulated Dursban provided significantly ($P < 0.01$) greater reduction in cockroaches compared to Combat bait trays.

Only a small percentage of oriental cockroach populations infesting residential buildings have been reported to move to indoor living areas (sections 2.2.1. and 3.2.2). Oriental cockroaches generally seek harborage in basements, crawlspaces, wall and porch voids, and other areas with damp, porous surfaces. Effective reduction of cockroaches in these refuges is probably more dependent on the formulation than the insecticide molecule. Encapsulated formulations protect insecticides and prolong their residual activity. Granovsky (1985) reported that a one-time perimeter treatment with encapsulated diazinon around the perimeter of dwellings provided significant reduction of cockroaches and other insect pests. Although Combat baits were enclosed within bait trays, the formulation was not stable in high humidity. Eighty-two percent (23 of 28) of the remaining baits (23 of 28) were covered with mold, which may have deterred cockroach feeding.

4.2.2 Percentage Reduction: Structural Modification

In the pretreatment trap counts, the mean number of cockroaches trapped at modified and unmodified buildings were not significantly different (Table 8). At the 2, 4, 8, and 52 wk evaluations, cockroach populations at all four buildings were reduced compared to pretreatment intervals. Throughout the posttreatment trapping period, oriental cockroaches were not significantly ($P < 0.05$) reduced at modified buildings compared to unmodified buildings. After one year, the 79% reduction of cockroaches at the sprayed, unmodified building (Cont 1) was greater than the percent reduction at the two modified buildings (Mod 1 and 2, Fig. 12). Approximately equal numbers of oriental cockroaches were trapped indoors at the two modified buildings (18 cockroaches) and at the two unmodified buildings (17 cockroaches) during the summer of 1985.

There may be several reasons why structural modification was not more effective in controlling cockroaches. Modification did not eliminate access to all potential harborage areas. Oriental cockroaches relocated to new harborage sites, such as gaps where the cellar well casing had separated from the foundation (Mod 1), and spaces formed by ground settling beneath new walkways (Mod 2). Farmer and Robinson (1984) also reported the difficulty of sealing all access to harborage for control of German cockroaches. They observed no significant difference in cockroach control between uncaulked and caulked apartments in which only 41% of the internal cracks and crevices could be sealed. Building deterioration is a continual process. Additional loss of mortar facing (Mod 1) provided new access for oriental cockroaches into the cinder block foundation of the back porch.

4.2.3 Cost Evaluation

The cost of liquid insecticides per building, using a mean ± S.D. of 5.9 ± 1.5 liters per building, ranged from \$6.04 for encapsulated Dursban to \$1.24 for Dursban 4E (Table 9). A mean of 1.5 man-hours was required to treat each building. Cost of labor for maintenance personnel, based on \$10.00/hr for wages and \$2.50/hr (25%) for fringe benefits, would average \$12.50/hr (Roanoke Redevelopment and Housing Authority). Using maintenance personnel certified for pest control to treat a 50-building complex would cost \$1,240.00 using encapsulated Dursban, \$1,051.00 using KnoxOut, and \$1,000.00 using Dursban 4E (Table 10). These estimates do not include the cost of equipment or certification and insurance for pest control. A professional pest control company would charge about \$80.00 a building for treatment (J. Beck, personal communication) and about \$4,000.00 to treat a 50-building complex. Cost of insecticide probably would not alter this amount. Insecticides account for only 6-8.5% of a pest control company's total cost for treatment (Velsicol 1982). The added expense of using a more costly but more effective insecticide might be offset by intangible benefits such as reducing the number of buildings requiring retreatment. Most pest control companies guarantee their general pest control treatments for 30 days. Using encapsulated Dursban would cost $188.50 more than KnoxOut to treat a 50-building complex. However, the encapsulated Dursban replicates had 13.5% higher reduction in oriental cockroaches compared to KnoxOut treatments after four wks in the field evaluations (Table 6). Retreating three buildings would eliminate the cost advantage of a pest control company using the less effective, less expensive formulations to treat a 50-building complex.

The cost of 20 Combat bait trays per building was $7.50 (Table 9). A mean of one man-hour per building was needed to secure the bait trays to the outside substrate and in crawlspaces. Combat bait trays cost at least $1,000.000 to treat a 50-building apartment complex (Table 10), not including the cost for monitering and replacing empty bait trays. Treatments using Combat bait trays or Dursban 4E were comparable in cost and reduced oriental cockroach populations 50-76% or 78%, respectively, at eight wks postreatment.

The cost of materials for structural modification, excluding the insecticide application, averaged $14.00 per building (Table 11). The procedure was labor intensive, requiring 12 man-hours per building. The cost of insecticide treatments, $1,000.00 - $4,000.00 (Table 10), in addition to the cost of building repairs, $8,200.00, would bring the total expense of structural modification for a 50-building complex to $9,200.00 - $12,200.00.

4.2.4 Conclusion

To obtain an acceptable reduction in the oriental cockroach population throughout a summer would cost a 50-building apartment complex from $1,051.00 to $4,000.00 for one perimeter and crawlspace application of encapsulated chlorpyrifos or diazinon. Although the initial applications of Combat and Dursban 4E were equivalent in cost ($1,000.00), Combat baits molded in humid conditions and would require additional monitering and replacement of empty trays. The total cost of $9,200.00 - $12,200.00 for structural modification might be justified if modification reduced the need for annual insecticide applications. However, oriental cockroaches were not significantly reduced at modified buildings compared to unmodified buildings at one year posttreatment. Modified buildings still needed to be reinspected and repaired annually for damage leading to reinfestation.

TABLE 6

Insecticide formulations and percentage reduction of oriental cockroach populations, Roanoke, Va., 1985

Treatment	Pretreat trap counts[1]	Post treatment (wks) percentage reduction[2] 2	4	6	8[3]	12[3]
DursbanXRM	8.0 a	98.8 a	98.8 a	98.1 a	93.8 a	91.1 a
KnoxOut	7.2 a	91.8 ab	85.3 a	85.0 ab	91.9 ab	97.6 a
Dursban 4E	7.1 a	86.6 ab	94.5 a	87.4 ab	78.0 ab	95.0 a
Combat	7.1 a	70.7 b	65.3 a	63.6 b	49.7 b	67.7 ab
Control	5.8 a	-4.1 c	-47.4 b	-21.8 c	22.0 c	31.5 b

[1] Mean number of oriental cockroaches per trap. Means in a column followed by the same letter are not significantly different at $P < 0.05$ (Duncan's [1955] multiple range test).

[2] Percentage reduction in a column followed by the same letter are not significantly different at $P < 0.05$ (Duncan's [1955] multiple range test on transformed data - arcsine$\sqrt{\%}$).

[3] Percentage reduction corrected using Abbott's formula (1925).

TABLE 7

Bait remaining and % reduction in oriental cockroach populations following a Combat bait application, 1985

Replicate	Wt (g) of remaining bait (Mean ± S.D.)[1] Outside (N)	Crawlspace[2]	% reduction in cockroaches
1	0.4 ± 0.9 (5)	5.0 ± 1.9	69.3
2	0 (8)	3.7 ± 2.1	0
3	0.4 ± 0.7 (8)	3.5 ± 3.3	97.8

[1] Initial weight of bait: Mean ± S.D. = 6.8 ± 0.1g

[2] N = 10

TABLE 8

Structural modification and percentage reduction in oriental cockroach populations, Roanoke, Va., 1984-85

Treatment[1]	Pretreat trap counts[2]	Post treatment percentage reduction[3] 2 wks	4 wks	8 wks	1 year
Modified	3.4 a	96.6 a	100 a	82.0 a	54.8 a
Unmodified	2.8 a	87.1 a	84.8a	77.8 a	50.5 a

[1] Both structurally modified buildings and one unmodified building were treated with Dursban 4E. One unmodified building was not treated with insecticides.

[2] Mean number of oriental cockroaches per trap outdoors. Means in a column followed by the same letter are not significantly different at $P < 0.05$ (Duncan's [1955] multiple range test).

[3] Percentage reduction in a column followed by the same letter are not significantly different at $P < 0.05$ (Duncan's [1955] multiple range test on transformed data - arcsine$\sqrt{\%}$).

TABLE 9

Cost of insecticide formulated materials

Insecticide	% A.I.	Cost ($) per unit finished product	Average cost ($)[4] per building
Combat	1.65	0.38/tray[1]	7.50
Dursban ME	0.50	1.02/liter[2]	6.04
KnoxOut	1.00	0.39/liter[3]	2.27
Dursban 4E	0.50	0.21/liter[3]	1.24

[1] Suggested retail price, American Cyanamid Co.

[2] Suggested retail price, Dow Chemical U.S.A; Dursban ME (micro-encapsulated) is similar in formulation to Dursban XRM 4808.

[3] Forshaw Chemicals, Inc. 1985 Price Catalogue.

[4] Based on 5.9 ± 1.5 liters of insecticide or 20 bait trays per building.

TABLE 10

Cost to treat a 50 building apartment complex for oriental cockroaches using inhouse pest control personnel

	Cost in $		
Treatment	Materials	Labor [1]	Total
Dursban ME	302.00	938.00	1,240.00
KnoxOut	113.00	938.00	1,051.00
Dursban 4E	62.00	938.00	1,000.00
Combat	375.00	625.00	1,000.00
Modification	700.00	7,500.00	8,200.00[2]

[1] Based on $12.50/hr for wages and fringe benefits.

[2] Does not include cost of insecticide pretreatment.

TABLE 11

Cost of materials used in structural modification

	Amount of Material			Av. cost ($) per building
	Rep 1	Rep 2	Average	
No. of vents screened	2	2	2	1.50 [1]
Caulking - m	22.8	36.3	29.6	11.00 [2]
Mortar - cm^2	4.1	7.8	6.0	1.50 [3]
Total cost				14.00

[1] $0.75 per vent for 71 cm wide aluminum window screening.

[2] $5.50 per container of Dow Corning silicon sealant: seals 17.4 linear m with 0.5 cm bead.

[3] $3.00 for 27.2 kg bag of mortar mix.

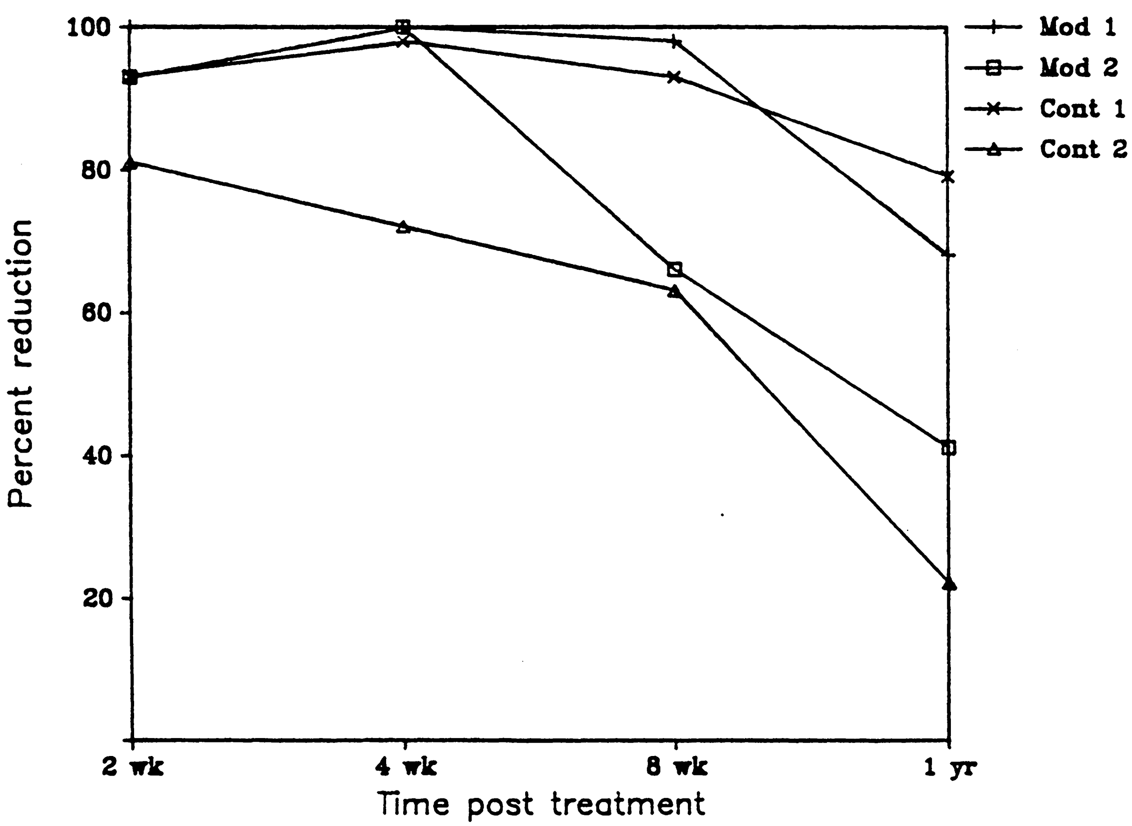


Figure 12: Percent reduction of oriental cockroach populations at modified & unmodified buildings, Roanoke, Va. 1984-85

Chapter V

POTENTIAL OF THE EVANIID WASP, PROSEVANIA PUNCTATA, AS A BIOLOGICAL CONTROL AGENT FOR THE ORIENTAL COCKROACH

One properly timed perimeter application of encapsulated chlorpyrifos or diazinon around dwellings was demonstrated in section 4.2.1 to significantly ($P < 0.05$) reduce oriental cockroach populations throughout their peak period. The potential of selecting for insecticide resistance in oriental cockroaches or toxifying nontarget organisms necessitates minimizing insecticide applications. Insecticide use could be reduced by integrating noninsecticidal methods, such as structural modification and trapping, into a managment program. However, there are problems associated with these alternative methods. Structural modification is a labor intensive procedure which may not significantly ($P < 0.05$) reduce oriental cockroach populations (section 4.2.2). Studies using sticky traps to reduce oriental cockroach infestations have yielded inconclusive results (Barak et al. 1977).

One noninsecticidal method for managing oriental cockroach populations which has not been investigated is the utilization of predators and parasites. House centipedes, Scutigera coleoptrata (L.) (Scutigeromorpha: Scutigeridae), and pholcid spiders, Pholcus phalangioides (Fuesslin) (Araneidae: Pholcidae), have been observed feeding on first instar oriental cockroach nymphs at RRHA buildings. These naturally occurring control agents probably would not be tolerated by residents; previous research has demonstrated that people generally dislike or fear myriapods and spiders (Thoms 1985). The evaniid wasp Prosevania punctata may be a more desirable control agent because residents have demonstrated some ability to tolerate the presence of this wasp in their homes (section 2.2.4). In addition, the distribution and life cycle of evaniid wasps and oriental cockroaches are closely synchronized (section 2.2.3).

More information is needed on the interactions of P. punctata with its host and human residents to evaluate the efficacy of conserving and augmenting evaniid wasps for managing oriental cockroach populations. Parasitization rates of oriental cockroach oothecae by P. punctata under laboratory and field conditions have not been evaluated (Edmunds 1952a, 1952b, 1953, 1954). One reason for this may be because oriental cockroach oothecae are difficult to locate in field conditions (Rau 1924, Piper et al. 1978). In addition, the longterm potential of educational programs for increasing the number of residents who would tolerate evaniid wasps has not been investigated (section 2.2.5).

The purpose of the research reported here was to evaluate of P. punctata as a biological control agent of the oriental cockroach. The specific objectives were to determine 1) the oviposition potential of P. punctata and oriental cockroaches in laboratory and field studies, and 2) the potential of residents for learning to tolerate P. punctata.

5.1 MATERIALS AND METHODS

5.1.1 Oriental Cockroach Oviposition Potential

The oviposition potential of oriental cockroaches was studied under laboratory conditions. On May 29, 1985, adult oriental cockroaches were trapped at RRHA apartment buildings. Fifty individual male:female pairs of cockroaches were separated in 0.47 liter plastic containers with screened lids and were supplied with water and dog food pellets. Cockroaches were checked daily for production of oothecae. Deposited oothecae were removed and individually placed in 29.6 ml plastic cups. Cockroaches and oothecae were maintained in environmental chambers at 25° ± 2° C, 14 h:10 h (L:D) photoperiod, and 50% ± 10% RH. The dates of ootheca deposition and cockroach emergence, and number of nymphs per ootheca were recorded for each female cockroach.

5.1.2 Evaniid Wasp Oviposition Potential

The oviposition potential of evaniid wasps was studied under laboratory and field conditions. Evaniid wasps collected by RRHA residents from August 1983 to August 1985 were used to initiate and augment a VPI & SU culture. In the laboratory, male:female pairs of newly emerged adults were placed in modified 0.65 liter plastic containers. The influence of age and species of ootheca on parasite oviposition and development were evaluated. A replicate consisted of the oviposition history of one female wasp. Replicates were discarded if females survived less than four days or did not oviposit. To determine the influence of age of ootheca, individual female wasps were exposed to six oothecae daily, two oothecae from each of three age groups; 1 day, 14 days, and 28 days (21 replicates). To determine the influence of species of ootheca, individual female wasps were exposed to four one-day old oothecae daily, two American and two oriental cockroach oothecae (32 replicates). Cockroach oothecae were obtained from VPI & SU stock cultures. Oothecae were removed after a 24 h exposure period and individually placed in 29.6 ml plastic cups. Adult wasps and oothecae were maintained in environmental chambers at 27° ± 2° C and similar photoperiod and RH as previously described. The following parameters were measured; percentage parasitization, time spent in the ootheca (egg-pupal period), percentage adult emergence, and gender and longevity of adult wasps.

Field parasitization rates of evaniid wasps were evaluated using two techniques: seeding oothecae indoors in apartments, and surveying existing oothecae outdoors in weepholes (narrow openings for ventilating wall voids). The use of trap hosts, such as cockroach oothecae, is an effective index of parasitization and a convenient alternative to sampling populations in which the parasitized stage is difficult to locate (Coler et al. 1984). Two Lansdowne Park buildings, each with four apartments, were seeded with oothecae from June 24 to August 15, 1985. One-day old oriental cockroach oothecae from VPI & SU cultures were individually attached with Elmer's® glue to cardboard mounted in 3.0

cm plastic disks. Laboratory tests demonstrated no difference between unattached oothecae and glue-attached oothecae in percentage parasitization. Plastic disks were attached with Velcro® strips beneath kitchen and bathroom sinks. There were two disks per apartment, totalling eight disks per building. Oothecae were replaced weekly and maintained in environmental chambers at the similar conditions described for the wasps. To monitor the evaniid wasp population indoors, resident cooperators in three apartments, including one resident from each seeded building, collected wasps from April through August 1985 using the methods described in section 2.1.4. These residents were reliable cooperators based on their wasp collection data from 1983 and 1984 (section 2.1.4).

Oriental cockroach oothecae were found in weepholes of RRHA apartments during the summer of 1985. From September 4 to 11, 1985, cockroach oothecae were removed from weepholes at all 66 apartment buildings in the Lansdowne Park complex. The number of weepholes and the number and condition of oothecae per weephole were recorded for each building. Viable oothecae were placed in environmental chambers to rear parasites, if present. Empty oothecae containing septate divisions and a split keel were classified as hatched. Empty oothecae containing no septate divisions, an intact keel, fecal masses, and characteristic emergence holes were classified as previously parasitized. The species of parasite was identified by the number, size, and appearance of emergence holes. Adult _P_. _punctata_ chew one hole ca. 3.0 mm in diameter with rough edges. Adults of a second parasite, the eulophid Tetrastichus hagenowii, chew one to three holes each less than 1.0 mm in diameter with smooth edges.

5.1.3 Resident Education Program and Evaluation

In 1984, 151 residents of two RRHA complexes, Lansdowne Park and Lincoln Terrace, were interviewed to assess their knowledge and attitudes toward oriental cockroaches and evaniid wasps (chapter 2). An educational program involving written and audiovisual materials was designed using these survey results. During the first week of June 1985, brochures were mailed to all 597 residents of Lansdowne Park and Lincoln Terrace. The brochure used text and illustrations to describe evaniid wasps, identified as "ensign bugs" (Fig. 13), and to explain how residents could help control oriental cockroaches. The brochure advertised that residents who attended community meetings on cockroach control would receive a free can of an aerosol insecticide. Color slide presentations reviewing concepts presented in the brochure were held at both complexes on June 17, 1985. A total of 65 (11%) residents attended the two presentations.

To evaluate the education program, a randomized quota system was used (Miller 1977). Residents were subdivided into three groups based on their involvement in the learning about evaniid wasps; attending the slide presentation, being interviewed in 1984, or only receiving the brochure. Within each subdivision, ca. 20 residents were randomly selected to be interviewed at each complex. The method for conducting the interviews was described in section 2.1.2. The common name "evaniid wasp" was not used during the survey. Instead, respondents were referred to live specimens in clear plastic vials.

From July 15 to August 5, 1985, 115 residents were surveyed. To compare resident perceptions of evaniid wasps before and after the educational program, respondents were asked five questions previously used in the 1984 survey (section 2.1.2). Respondents were shown a live evaniid wasp and asked, "Have you seen this type of insect in your home during the past six months?" To determine the distribution and abundance of evaniid wasps, residents who had seen the wasps were asked, "Where around your home have you seen them (evaniid wasps)?" and "During spring and summer, how many of these insects do you find in your home during a one week period?" The pest status of evaniid wasps was evaluated by asking, "What do you do with these insects (evaniid wasps) when you find them?" and "Do you consider them to be a problem?" Respondents were asked five questions evaluating the educational program. Questions assessing quality and mode of information transfer were "Can you tell me what you know about this insect (evaniid wasp), such as its name or what it eats?" and, if the respondent could identify the wasp, "Where did you learn this information?" Questions evaluating the brochure were "Did you receive this brochure (respondent was shown the brochure) in the mail?" (If yes) "Do you still have this brochure?"

5.1.4 Data Analysis

For the evaniid wasp laboratory studies, percentage parasitization, developmental time, and adult longevity of wasps were ranked using Friedman's ranking procedure (SAS 1982b). The association between ranked data and the species or age of the cockroach ootheca was measured using ANOVA or GLM (SAS 1982b). A distribution free multiple comparisons test based on Friedman's rank sums was used to separate treatment means (Hollander and Wolfe 1973). For the evaniid wasp field studies, parasitization rates were correlated with number and infestation rate of cockroach oothecae using Pearson product-moment correlation procedure (SAS 1982a). The proportion of oothecae parasitized by the two parasites was compared using a Z test (Lentner 1975). For the survey, the association between 1985 survey responses and demographic variables, education program participation, or 1984 survey responses was tested using a X^2 test frequency procedure (SAS 1982a).

5.2 RESULTS AND DISCUSSION

5.2.1 Oriental Cockroach Oviposition Potential

Forty-seven of the fifty (94%) female cockroaches produced oothecae. Each of these females produced from one to 28 oothecae ($\overline{X} \pm SD = 9 \pm 7$) of which 77% were viable. The results of this experiment were similar to results of other studies on oriental cockroach oviposition (Rau 1924, Gould and Deay 1940, Willis et al. 1958). Gould and Deay

(1940) reported that oriental cockroach females produced from one to 18 oothecae ($\overline{X} \pm SD = 8 \pm 6$) of which 42% were viable. Viable egg cases contained a mean of 15 eggs (Table 12), which has been reported by other researchers (Rau 1924, Willis et al. 1958). The developmental time for oothecae ranged from 42 to 70 days ($\overline{X} \pm SD = 57 \pm 4$). In other investigations, the mean developmental time for oothecae maintained at room temperature varied from 50 days (Rau 1924) to 61 days (Gould and Deay 1940). The mean oviposition potential was 99 live nymphs per female (Table 12). The total number of oothecae produced weekly decreased throughout the summer as females aged and died (Fig. 14).

5.2.2 Evaniid Wasp Oviposition Potential

In the laboratory tests, parasitization rates of evaniid wasps were dependent on the age and species of cockroach oothecae (Table 13). In the age preference test, each female wasp parasitized a mean of 8.4 oothecae. Significantly ($P < 0.05$) more 1-day old oothecae (34%) compared to 28-day old oothecae (17%) were parasitized. The development time from egg through pupa and adult longevity were not dependent on ootheca age ($P > 0.05$). The ratio of emerging female:male wasps was 1.1:1 and also was not dependent on ootheca age ($X^2 = 1.35$, df = 2, $P > 0.50$). In the species preference test, each female wasp parasitized a mean of 10.1 oothecae. Significantly more oriental cockroach oothecae (51%) compared to American cockroach oothecae (23%) were parasitized ($F = 139.09$, df = 1, $P < 0.001$). The developmental time of parasites in oriental cockroach oothecae compared to American cockroach oothecae was significantly longer, 70 days vs. 55 days, respectively ($F = 16.31$, df = 1, $P < 0.001$). Adult longevity was not dependent on species of ootheca. The ratio of emerging female:male wasps was 2.2:1 and also was not dependent on species of ootheca ($X^2 = 0.02$, df = 1, $P > 0.50$). The ovipositional preference for oriental cockroach oothecae was not dependent on the species of ootheca from which the ovipositing female wasps developed; the proportions of American and oriental oothecae parasitized by females reared from American or oriental cockroach oothecae were not significantly different ($X^2 = 0.35$, df = 1, $P > 0.50$). Oriental cockroach oothecae may be preferred because they are larger than American cockroach oothecae and could provide more resources for parasite larval development.

In the field tests, none of the oothecae seeded in buildings were parasitized despite the presence of evaniid wasps indoors during the test period. A total of 20 evaniid wasps (9 males, 11 females) was collected indoors by resident cooperators from June 24 to August 15, 1985. Resident cooperators began to find evaniid wasps in their homes about two weeks earlier in 1985 compared to 1984. The three population peaks in late April-early May, early June, and mid-July for evaniid wasps collected in 1985 (Fig. 14) occurred about two weeks earlier than the three population peaks in 1984 reported in section 2.2.3. Reasons for absence of parasitization of seeded oothecae might have been low density of oothecae and inappropriate exposure sites. In a study by Coler et al. (1984), ten brownbanded cockroach oothecae were seeded weekly in a 2.4 by 5.2 m room in the same oviposition sites of naturally occurring egg cases. The seeded oothecae were readily parasitized by an encyrtid wasp, Comperia merceti (Compere). In this investigation, eight oothecae were placed weekly in an 8 by 24 m building; placement of oothecae at natural oviposition sites was not possible.

A total of 646 oothecae was recovered from weepholes surveyed in September 1985. From one to 58 oothecae ($\bar{X} \pm SD = 11 \pm 12$) were found at each of 60 buildings; no oothecae were recovered at six buildings. The number of weepholes per building ranged from 17 to 51 ($\bar{X} \pm SD = 32 \pm 6$). Two to 64% ($\bar{X} \pm SD = 17\% \pm 12\%$) of the weepholes were infested and contained 1-17 oothecae per weephole.

The low number of oothecae recovered from weepholes indicated that the cockroach infestations were being maintained by oothecae laid in other locations. In the 1984 mark-recapture study described in chapter 3, approximately 200 adult female cockroaches were marked at each of four buildings (Table 4). Based on the previous oriental cockroach oviposition study in which 94% of the females oviposited and each produced a mean of 9 oothecae, the estimated annual production of oothecae per building would be 1690. The mean number of oothecae (11) recovered in weepholes of each infested building may represent less than 1% of the total number of oothecae produced annually. The high parasitization rate of 51% observed for the small proportion of oothecae exposed in weepholes may not represent the majority of oothecae, which are probably concealed within foundation and porch voids.

Eight percent of the oothecae recovered from weepholes were inviable and 41% had hatched or contained live nymphs (Table 14). About 51% of the oothecae had been parasitized, 15% by the evaniid wasp P. punctata and 36% by the eulophid wasp T. hagenowii. The total number of oothecae per building was correlated with the number of oothecae parasitized by eulophids ($r = 0.900$) but not with the number of oothecae parasitized by evaniids ($r = 0.505$). In fact, the proportion of oothecae parasitized by evaniid wasps decreased as the percentage of weepholes infested with oothecae increased (Fig. 15). When 10% or less of the weepholes were infested, the proportions of oothecae parasitized by evaniids or eulophids were not significantly different (Z test, $P > 0.05$). When more than 10% of the weepholes were infested, significantly more oothecae were parasitized by the eulophid wasps than by the evaniid wasps (Z test, $P < 0.05$).

The eulophid wasp T. hagenowii possesses several physiological characteristics which make it more efficient than evaniid wasps as a control agent for Blatta and Periplaneta cockroach species. The developmental time from egg to adult is shorter for T. hagenowii than for P. punctata, 24 - 64 days vs. 37 - 337 days, respectively (Vargas and Fallas 1974, Fleet and Frankie 1975, Edmunds 1955, Usman 1949, and Narasimham 1984). In addition, T. hagenowii is a gregarious parasite with a mean of 30 to 93 adults emerging per cockroach ootheca (Vargas and Fallas 1974, Fleet and Frankie 1975, Edmunds 1955, Roth and Willis 1954, Cameron 1955, Usman 1949). In contrast, P. punctata is a solitary parasite with only one adult emerging per cockroach egg case. The shorter developmental time and greater reproductive potential of eulophid wasps, compared to evaniid wasps, enable eulophids to respond more rapidly to exploit increasing cockroach populations. In this study, the parasitization rate of oriental cockroach oothecae by T. hagenowii in field conditions increased to a maximum of 66% as the cockroach infestation level increased (Fig. 15). High parasitization rates by T. hagenowii in field conditions have also been reported for oothecae of Periplaneta species; 46% for P. australasiae (Vargas and Fallas 1974), 93% for P. fuliginosa (Wen-qing 1984), and 71% for P. americana (Piper et al. 1978).

5.2.3 Resident Education Program Evaluation

The duration of residency for survey respondents ranged from < 1 year to 33 years ($\overline{X} \pm SD = 12 \pm 10$). Respondents ranged in age from 16 to 89 years ($\overline{X} \pm SD = 48 \pm 19$). There was no significant difference between the 1985 and 1984 surveys in the mean years of residency ($F = 0.61$, $df = 1$, $P > 0.25$) or mean age of respondents ($F = 0.08$, $df = 1$, $P > 0.25$). A significantly higher percentage , 89% ($X^2 = 6.073$, $df = 1$, $P < 0.025$), of the respondents were female in the 1985 survey compared to the 1984 survey. Seventy-five percent of the respondents were black and the remainder were Caucasian.

The 1985 education program did not affect residents' perceptions of evaniid wasp distribution and abundance. Approximately 60% of the respondents in 1985 and 1984 had seen evaniid wasps in their homes. At least 12% more residents had seen the wasps in the kitchen compared with other rooms (Table 15). There was no significant difference between the 1985 and 1984 surveys in the proportion of respondents sighting evaniid wasps ($X^2 = 0.002$, df = 1, $P > 0.50$) and the location of wasps in the homes (df = 1, $P > 0.10$). Respondents estimated they saw a mean of 3.6 ± 4 evaniid wasps in 1985 and 3.5 ± 4 wasps in 1984 per week during the spring and summer in their apartments.

The education program did reduce the pest status of evaniid wasps. Significantly fewer respondents in 1985 (13%) compared to those in 1984 (27%) considered evaniid wasps to be a problem ($X^2 = 4.88$, df = 1, $P < 0.05$). Size of parasites is an important consideration in an urban environment. University of California employees accepted inundative releases of the encyrtid wasp C. merceti to control brownbanded cockroaches because this wasp is small and inconspicuous (Slater et al. 1980). The eulophid wasp T. hagenowii is less conspicuous than the evaniid wasp P. punctata due to its smaller size, 2.0 mm vs 8.0 mm in length, respectively. The eulophid wasp was not noticed by RRHA residents and may be a more desirable biological control agent than the evaniid wasp to utilize in the presence of people.

Significantly fewer respondents in 1985 (59%) compared to those in 1984 (89%) killed the evaniid wasps they found ($X^2 = 18.98$, df = 1, P <

0.001). The impact of the destruction of evaniid wasps by residents on survival of oriental cockroach oothecae is difficult to evaluate. If residents would not kill wasps found indoors, these insects could possibly help to reduce oriental cockroach populations. From April 18 through August 25, 1985, resident cooperators collected a mean of 12 female evaniid wasps per apartment. Based on the evaniid wasp parasitization study in which 95% of the females oviposited and each parasitized a mean of nine oothecae, the estimated number of oothecae parasitized by wasps found indoors at one building (four apartments) would be 410. The number of evaniid wasps found indoors could parasitize up to 24% of the estimated 1690 oothecae produced annually per building. This estimate may be exaggerated, because the oviposition history of female wasps before being found indoors was not known.

Educational methods involving face to face contact, such as the 1984 interview and the slide presentation, were more effective than the brochures for informing residents. Twenty-seven percent of the respondents could identify the evaniid wasp or knew that the insect fed on cockroach eggs. The ability of respondents to identify the evaniid wasp was dependent upon their experience in the education program ($X^2 = 6.97$, df = 2, $P < 0.05$). Wasps were identified by 38% of the residents participating in the 1984 survey, by 32% attending the slide presentation, and by 13% participating in neither activity, receiving only the brochure. Forty-eight percent of these residents remembered learning this information from the 1984 interview, 29% from the slide presentation, and 19% from the brochure. Mass mailing of brochures was an inefficient educational tool. Thirty-nine percent of the respondents said they never received the brochure and only 38% of the respondents read or saved the brochure. Whether or not residents saved the brochure was dependent upon their participation in the education program (X^2 = 6.61, df = 2, P = 0.05). Brochures were saved by 80% of the residents attending the slide presentation, by 68% participating in the 1984 survey, and by 44% participating in neither activity.

Respondents' ability to tolerate or identify wasps was related to their race. Significantly greater proportions of blacks (67%) compared to Caucasians (39%) killed the evaniid wasps they found (X^2 = 4.26, df = 1, $P < 0.05$). Significantly lower proportions of blacks (22%) compared to Caucasians (41%) knew the name and feeding habits of evaniid wasps (X^2 = 3.95, df = 1, $P < 0.05$). This difference may be due to the racial heterogeneity between the Caucasian interviewers/educators and black residents. Reseachers have demonstrated that racial homogeneity is important in developing rapport between interviewers and respondents (Hymen 1954).

The results of the education program indicate that techniques providing personal contact and establishment of rapport would be most efficient for transferring information. Pest control technicians could be trained for the dual responsibilities of pest control and resident education. Elevating technicians to the role of educator may have additional benefits, such as reducing job monotony, encouraging resident involvement in pest control, and enhancing the professional image of pest control personnel.

5.2.4 Conclusions

Oriental cockroach oothecae collected in weepholes of RRHA buildings represented less than 1% of the estimated total number of oothecae produced annually per building. Therefore, the actual parasitism rate by the evaniid-eulophid wasp complex of oothecae concealed in foundation voids may be less than the 51% parasitism rate observed for oothecae exposed in weepholes. The evaniid wasp *P. punctata* is less efficient than the eulophid wasp *T. hagenowii* as a biological control agent of the oriental cockroach. In laboratory conditions, the maximum parasitization rate of oriental cockroach oothecae by evaniid wasps was 51%. In field conditions, the maximum parasitization rate of oriental cockroach oothecae by evaniid wasps was 35%, which decreased as the cockroach infestation level increased (Fig. 15). Even after an intensive education program, nearly 60% of the residents still killed evaniid wasps when they found them. The eulophid wasp *T. hagenowii* has a shorter developmental period, higher reproductive potential, higher field parasitization rate, and less conspicuous appearance compared to *P. punctata*. *T. hagenowii* merits furthur investigation as a naturally occurring control agent for oriental cockroaches.

Successful utilization of parasites for managing cockroach populations has been limited to unique situations, such as animal research facilities where use of insecticides would disrupt research (Slater et al. 1980). Parasite release programs are labor intensive and provide variable results. At the University of California, augmenting C. merceti populations for brownbanded cockroach control required maintaining parasite cultures, releasing parasites weekly in infested areas, and monitoring establishment of parasites (Slater 1984, Slater et al. 1980). Efficacy of these inundative releases for reducing cockroaches was variable depending on environmental conditions and cooperation from University employees. Most important, at optimum conditions for the host the parasite was not effective (Slater 1984).

The availability of insecticide formulations in which the toxicant is protected in tamper-proof containers, or in which the active ingredient is not toxic to nontarget organisms (i.e. insect growth regulators), may diminish the usefulness of parasites for controlling structural and household insect pests. These insecticide formulations, compared to augmenting parasites, are less labor intensive to apply, provide reliable control, and may be used in sensitive areas where conventional insecticide applications are not possible. The problems associated with releasing parasites in the urban environment and the availability of target-specific insecticides should prompt entomologists to carefully evaluate use of parasites to manage structural and household insect pests.

TABLE 12

Reproductive potential of female oriental cockroaches collected in Roanoke, Va. in May 1985[1]

Ootheca[2] condition	N	X ± SD (Range) Eggs/ootheca	Oothecae/female	Nymphs/female
Viable	322	15 ± 1 (9-17)	7 ± 5 (1-18)	99 ± 76 (13-260)[3]
Inviable	98	14 ± 2 (8-19)	2 ± 3 (0-14)	29 ± 43 (0-208)[4]

[1] 47 females - oviposition from June 3, 1985 to February 6, 1986.

[2] Nymphs emerged from viable oothecae; no nymphs emerged from inviable oothecae

[3] Live nymphs/female

[4] Dead nymphs/female

TABLE 13

Effect of age and species of cockroach ootheca on evaniid parasitization parameters

	Parasitization Rate (%)[3]	Developmental Time (Days)[3]	Adult longevity (Days)[3]
Oothecal age[1]			
1 day	33.6 a	97.6 a	10.3 a
14 days	24.8 ab	109.1 a	11.0 a
28 days	16.9 b	73.1 a	11.7 a
Oothecal spp.[2]			
Oriental	51.0 a	70.0 a	11.5 a
American	23.2 b	55.3 b	10.7 a

[1] N = 21 female wasps

[2] N = 32 female wasps

[3] For each test, values within a column followed by the same letter are not significantly ($P < 0.05$) different using multiple comparison procedure based on ranksums.

TABLE 14

Condition of oriental cockroach oothecae found in weepholes, 60 buildings, Roanoke, Va. 1985

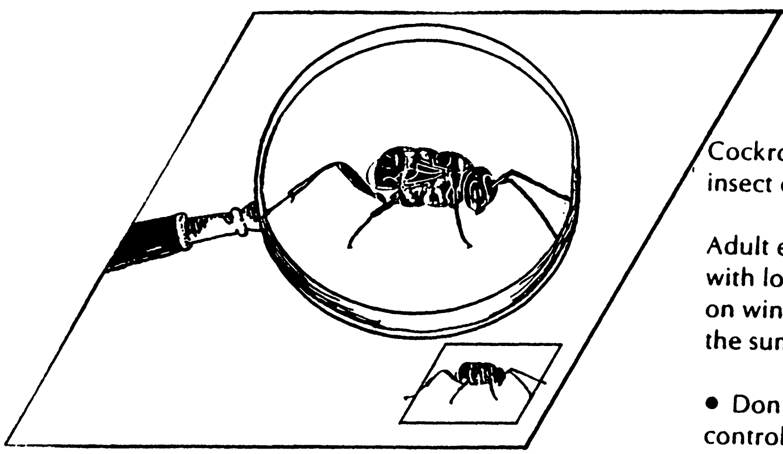
		$\overline{X}$ ± SD (Range) of oothecae per building	
Oothecal condition	N	Number	Percent (%)
Hatched or viable	226	4 ± 4 (0-25)	41 ± 30 (0-100)
Inviable	66	1 ± 2 (0-11)	8 ± 14 (0- 60)
Parasitized:			
Evaniids	75	1 ± 2 (0- 8)	15 ± 20 (0-100)
Eulophids	279	5 ± 8 (0-35)	36 ± 30 (0-100)

TABLE 15

Resident sightings of evaniid wasps in apartments, Roanoke, Va., 1984 and 1985

Positive response[1]	1984 (%)	1985 (%)
Kitchen	54	51
Living room	41	39
Bathroom	40	38
Bedrooom(s)	35	38
Outdoors	12	17

[1] Responses of residents in 1984 and 1985 were not significantly different ($P > 0.25$, X^2 test).



Cockroach eggs are eaten by a small insect called an "Ensign-bug."

Adult ensign-bugs look like black flies with long black legs. They are found on window and door screens during the summer.

- Don't kill ensign-bugs — they help control cockroaches.

Figure 13: Section of brochure describing evaniid wasps

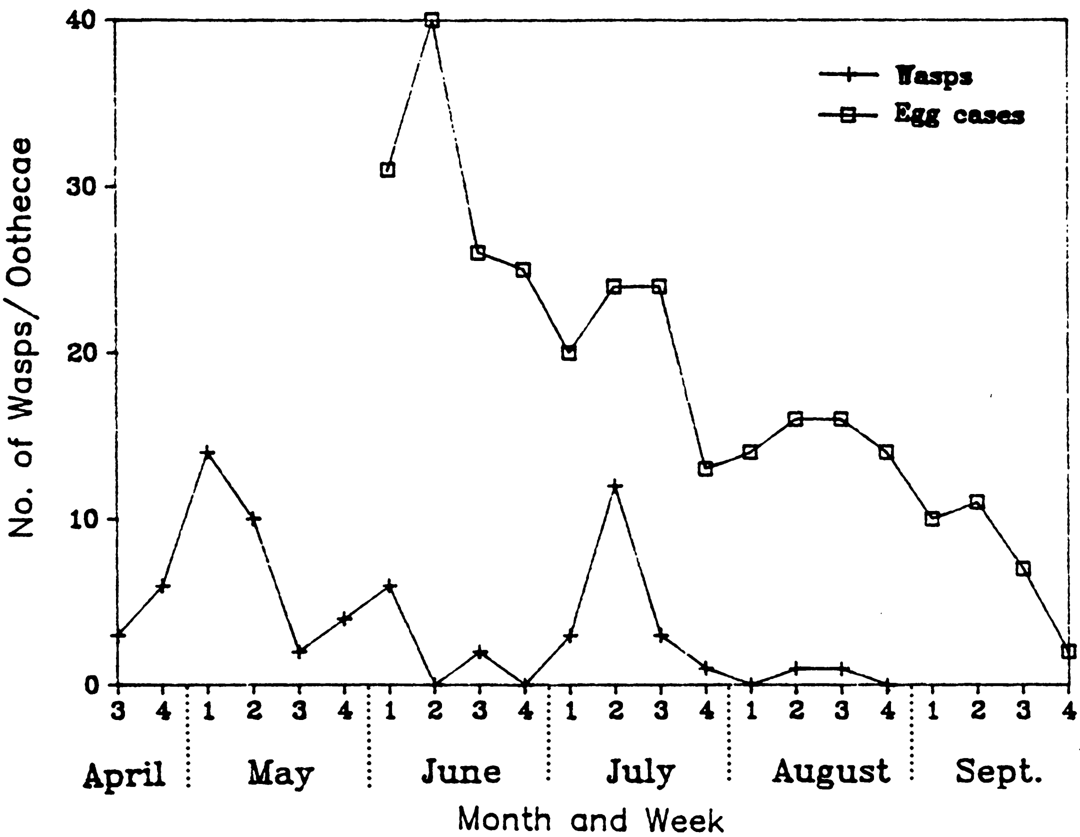


Figure 14: Total number of field-collected evaniid wasps and lab-produced oriental cockroach oothecae, 1985

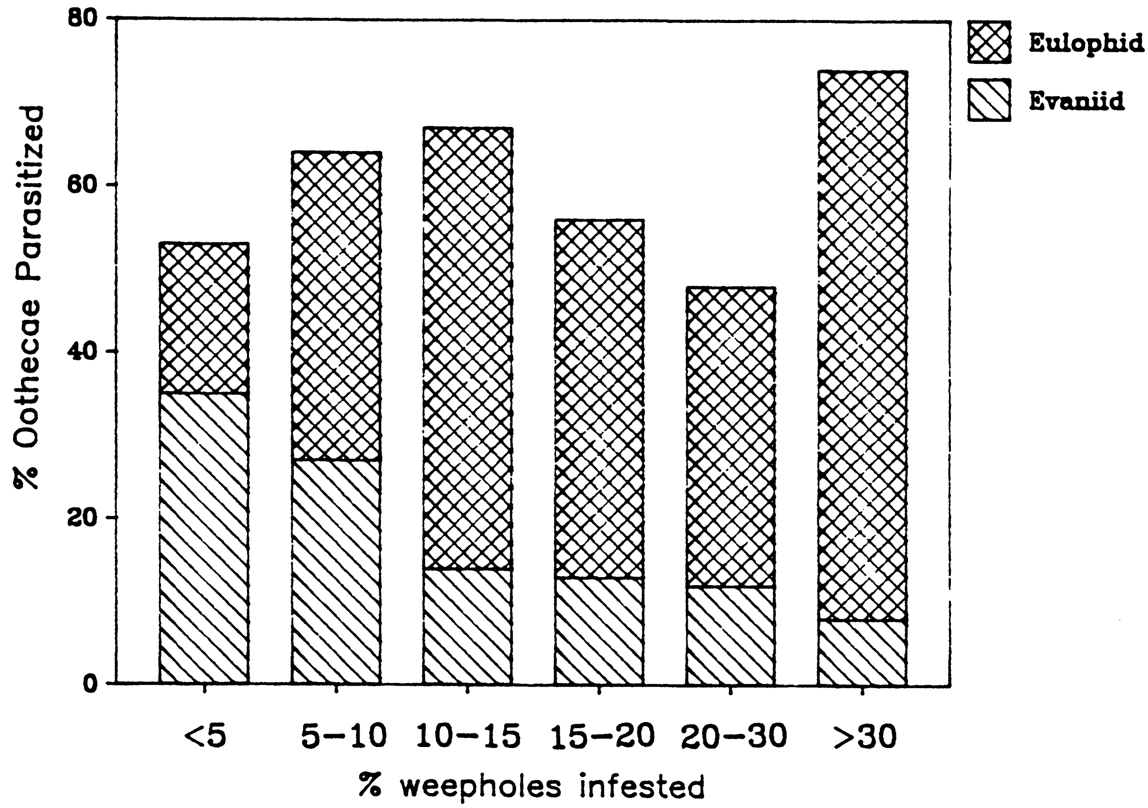


Figure 15: Proportions of oriental cockroach oothecae in weepholes parasitized by evaniid and eulophid wasps, Roanoke, Va., 1985

Chapter VI

A PEST MANAGEMENT PROGRAM FOR THE ORIENTAL COCKROACH

The results of the research presented here can provide guidelines for an oriental cockroach pest management program. The components of this program would be to; 1) train the management and pest control personnel, 2) assess the cockroach infestation level and the attitudes of the target audience, 3) develop a management strategy utilizing appropriate techniques, 4) educate the target audience, and 5) evaluate the program in terms of cockroach reduction and audience satisfaction. A similar outline for a German cockroach pest management program was developed by Robinson and Zungoli (1985).

6.1 TRAINING PROGRAM

Management personnel need to be kept informed of, and pest control personnel should participate in, all phases of the program; its development, implementation, and evaluation. Training sessions for reviewing oriental cockroach biology and control techniques are necessary to provide these personnel with an understanding of the target pest and the importance of creating a management program. Pest control personnel will need additional training on how to respond to resident/client questions, insecticide application techniques, the care of equipment, and job safety (Robinson and Zungoli 1985).

6.2 ASSESSMENT OF PROBLEM

Surveys of oriental cockroach infestation levels and audience attitudes should be conducted concurrently to evaluate perceived versus actual conditions concerning insect distribution and abundance (section 2). Sticky traps are effective for monitoring oriental cockroach populations (Moore and Granovsky 1983, section 3.2.1). Traps should be placed at standardized locations indoors near cockroach entry routes, i.e. under bathroom and kitchen sinks (section 2.1.3), and outdoors near potential harborage sites such as porches and crawlspace vents (section 2.1.3). A standardized questionnaire, similar to the one used in section 2.1.2, should be given to the target audience to evaluate their perceptions of the current pest problem. In-house pest control personnel should be trained to participate in trapping cockroaches and interviewing the target audience. It is important for pest control personnel to establish a rapport with their audience (section 5.2.3).

6.3 SPECIFIC CONTROL TECHNIQUES

Oriental cockroaches tend not to move between adjacent buildings which are separated by 6 m or more (section 3.2.2). Therefore, only infested structures need to be treated with insecticides for immediate reduction of oriental cockroach populations. Encapsulated formulations are currently the most effective for application outdoors and in crawlspaces and basements (section 4.2.1). The exterior perimeter foundation and interior walls of the crawlspace or basement around vents or windows should be treated prior to the adult population peak in late June and July (section 3.2.3). Encapsulated or emulsifiable concentrate formulations are suitable for application indoors. Entrance routes for oriental cockroaches, openings in walls where plumbing enters and door thresholds, should be treated. The effects of insecticides on evaniid and eulophid parasites developing in oriental cockroach oothecae are unknown. Therefore, no recommendations can be made for insecticide application methods which would least disrupt the development of these parasites.

Structural modification to "cockroach-proof" a building by reducing access of oriental cockroaches to harborage sites, does not significantly ($P < 0.05$) reduce oriental cockroach populations (section 4.2.2) and is labor intensive (section 4.2.3). Structural modification to restrict oriental cockroach movement indoors may be more practical. Gaps in walls where pipes enter rooms should be sealed and tight-fitting weather stripping should be installed around doors (section 3.2.3).

6.4 EDUCATION PROGRAM

Educational methods involving face to face contact are the most effective for transferring information (section 5.2.3). Pest control personnel should consider resident/client education as one of their responsibilities and as an important component of the program. Information on managing oriental cockroaches could be described in an illustrated brochure (section 5.1.3.) which the pest control personnel would distribute and briefly review with members of the target audience. Educating residents to conserve large parasites, such as evaniid wasps, for oriental cockroach management probably would not be cost effective because residents are generally intolerant of conspicuous insects found indoors (section 5.2.3). Educating residents to conserve small parasites, such as eulophid wasps, may be unecessary because residents do not notice these inconspicuous insects.

6.5 EVALUATION

Surveys of oriental cockroach infestation levels and audience attitudes should be conducted again after implementation of the management program and their results compared with those of the preliminary surveys (Robinson and Zungoli 1985). The seasonal life cycle of the oriental cockroach must be considered when evaluating the program results (section 1.4.1).

Pest management programs must balance the often conflicting expectations of a target audience for safety, pest reduction, and cost effectiveness. The research presented here has helped to develop reasonable guidelines for an oriental cockroach pest management program and has created a foundation for further investigations of this worldwide pest.

REFERENCES CITED

Abbott, W. S. 1925. A method for computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

Akers, R. C., and W. H Robinson. 1981. Spatial pattern and movement of German cockroaches in urban, low-income apartments (Dictyoptera: Blattellidae). Proc. Entomol. Soc. Wash. 83: 168-172.

-------- 1983. Comparison of movement behavior of three strains of German cockroach, Blattella germanica. Entomol. Exp. & Appl. 34: 143-147.

Anonymous. 1957. Oriental cockroaches from sewers. Pest Control 25(2): 26, 46.

Appel, A. G., and M. K. Rust. 1985. Outdoor activity and distribution of the smokybrown cockroach, Periplaneta fuliginosa (Dictyoptera: Blattidae). Environ. Entomol. 14: 669-673.

-------- 1986. Time-activity budgets and spatial distribution patterns of the smokybrown cockroach, Periplaneta fuliginosa (Dictyoptera: Blattidae). Ann. Entomol. Soc. Am. 79: 104-108.

Ballard, J. B., H. J. Ball, and R.E. Gold. 1984. Influence of selected environmental factors upon German cockroach (Orthoptera: Blattellidae) exploratory behavior in choice boxes. J. Econ. Entomol. 77: 1206-1210.

Ballard, J. B., and R. E. Gold. 1984. Biology and management of Wood and Oriental cockroaches in the near environment. Pest Manage. 3(7): 20-25.

Barak, A. V., M. Shinkle, and W. E. Burkholder. 1977. Using attractive traps to help detect and control cockroaches. Pest Control 45(10): 14-16, 18-20.

Bell, W. J., T. Burk, and G. R. Sams. 1973. Cockroach aggregation pheromone: directional orientation. Behav. Biol. 9: 251-255.

Bell, W. J., C. Parsons, and E. A. Martinko. 1972. Cockroach aggregation pheromones: analysis of aggregation tendency and species specificity (Orthoptera: Blattidae). J. Kansas Entomol. Soc. 45: 414-421.

Burgess, N. R. H. 1984. Hospital design and cockroach control. Trans. Roy. Soc. Trop. Med. Hyg. 78: 293-294.

Burgess, N. R. H., K. N. Chetwyn, C. J. Nunn, and A. E. Shuttleworth. 1974. Some preliminary work on cockroach-infested sewers in London. Trans. Roy. Soc. Trop. Med. Hyg. 68: 16.

Burgess, N. R. H., S. N. McDermott, and J. Whiting. 1973. Aerobic bacteria occurring in the hind-gut of the cockroach, Blatta orientalis. J. Hyg. 71: 1-7.

Cameron, E. 1955. On the parasites and predators of the cockroach. I. Tetrastichus hagenowii (Ratz.) Bull. Ent. Res. 46: 137-147.

Cochran, D. G. 1982. Cockroaches - biology and control. W.H.O., Vector Biol. Control Div., Pub. 856.

-------- 1984. Insecticide resistance in cockroaches - is it at a cross road? Pest Manage. 3(8): 26-31.

Coler, R.R., R.G. Van Driesche, and J.S. Elkinton. 1984. Effect of an oothecal parasitoid, Comperia merceti (Compere)(Hymenoptera: Encyrtidae), on a population of the brownbanded cockroach (Orthoptera: Blattellidae). Environ. Entomol. 13: 603-606.

Cornwell, P. B. 1968. The cockroach. Vol. 1. Hutchinson and Co., Ltd. London.

Cornwell, P. B., and M. F. Mendes. 1981. Disease organisms carried by oriental cockroaches in relation to acceptable standards of hygiene. Intl. Pest Control 23(3): 72-74.

Denzer, V.D.J., M.E.A.Fuchs, and G. Stein. 1985. Radius of action, loyalty to the refuge, settlement of new refuges, and diurnal rhythm of Blatta orientalis L. in relation to population density and composition. Z. Ang. Ent. 99: 400-407.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-41.

Eads, R. B., F. J. Von Zuben, S.E. Bennett, and O. L. Walker. 1954. Studies on cockroaches in a municipal sewerage system. Am. J. Trop. Med. Hyg. 3: 1092-1098.

Ebeling, W. 1978. Urban Entomology. University of California, Division of Agricultural Sciences.

Edmunds, L. R. 1952a. A study of the biology and life history of Prosevania punctata (Brullé) with notes on additional species (Hymenoptera: Evaniidae). Ph.D. dissertation, Ohio State University, Columbus.

-------- 1952b. The oviposition of Prosevania punctata (Brullé): a hymenopterous parasite of cockroach egg capsules. Ohio J. Sci. 52: 29-30.

-------- 1953. Some notes on the Evaniidae as household pests and as a factor in the control of roaches. Ohio J. Sci. 53: 121-122.

-------- 1954. A study of the biology and life history of Prosevania punctata (Brullé) with notes on additional species (Hymenoptera: Evaniidae). Ann. Entomol. Soc. Am. 47: 575-592.

-------- 1955. Biological notes on Tetrastichus hagenowii (Ratzeburg), a chalcidoid parasite of cockroach eggs (Hymenoptera: Eulophidae; Orthoptera: Blattidae). Ann. Entomol. Soc. Am. 48: 210-213.

Eversole, J. W. 1971. Feeding of American and oriental cockroaches on baits imbedded in paraffin. J. Econ. Entomol. 64: 1316-1317.

Farmer, B. R., and W. H Robinson. 1984. Harborage limitation as a component of a German cockroach pest management program (Dictyoptera: Blattellidae). Proc. Entomol. Soc. Wash. 86: 269-273.

Fleet, R. R., and G. W. Frankie. 1974. Habits of two household cockroaches in outdoor environments. Texas Agric. Exp. Stn. Misc. Publ. 1153.

--------- 1975. Behavioral and ecological characteristics of a eulophid egg parasite of two species of domiciliary cockroaches. Environ. Entomol. 4: 282-284.

Fleet, R. R., G. L. Piper, and G. W. Frankie. 1978. Studies on the population ecology of the smokybrown cockroach, Periplaneta fuliginosa, in a Texas outdoor urban environment. Environ. Entomol. 7: 807-814.

Frishman, A. M., and I. E. Alcamo. 1977. Domestic cockroaches and human bacterial disease. Pest Control 45(6): 16, 18, 20, 46.

Gould, G. E. 1940. Effect of temperature upon the development of cockroaches. Purdue Univ. Agric. Exp. Sta. Bull. 451: 242-248.

Gould, G. E., and H. O. Deay. 1940. The biology of six species of cockroaches which inhabit buildings. Purdue Univ. Agric. Exp. Stn. Bull. 451: 1-31.

Granovsky, T. A. 1983. Effect of exterior surface texture on cockroach jar trap efficiency. Environ. Entomol. 12: 744-747.

Granovsky, T. 1985. Cut callbacks with perimeter treatments. Pest Control 53(6): 42-44.

Haber, V. R. 1920. Oviposition by an evaniid, Evania appendigaster Linn. Can. Entomol. 52: 248.

Harlan, H. J., and R. D. Kramer. 1981. Limited host specificity in Tetrastichus hagenowii (Ratzeburg). J. Ga. Entomol. Soc. 16: 67-70.

Hollander, M. and D.A. Wolfe. 1973. Nonparametric statistical methods. Wiley and Sons, New York.

Hymen, H. 1954. Interviewing in Social Research. Univ. Chicago Press.

Jackson, W. B., and P. P. Maier. 1955. Dispersion of marked American cockroaches from sewer manholes in Phoenix, Arizona. Am. J. Trop. Med. Hyg. 4: 141-146.

-------- 1961. Additional studies of dispersion patterns of American cockroaches from sewer manholes in Phoenix, Arizona. Ohio J. Sci. 61: 220-226.

Kanzler, W. W. 1972. Population behavior of cockroaches in relation to survival. Ph.D. dissertation, Univ. of Cincinnati, Cincinnati, Oh. (abstract).

Kellert, S. R. 1980. American attitudes toward and knowledge of animals: an update. Int. J. Stud. Anim. Prob. 1: 87-119.

Killough, R. A. 1958. Susceptibility of the oothecae of the American cockroach, Periplaneta americana Linn., to various insecticides. M.S. thesis, Purdue Univ., Lafayette, In.

Lentner, M.L. 1975. Introduction to applied statistics. Marvin Lenter, Blacksburg, VA.

Lucas, W. J. 1912. British Orthoptera in 1911. Entomologist 45: 114-117.

-------- 1922. Notes on British Orthoptera in 1921. Entomologist 55: 200-203.

Mampe, C. D. 1972. The relative importance of household insects in the continental United States. Pest Control 40(12): 24, 26-27, 38.

Mellamby, K. 1939. Low temperature and insect activity. Proc. Roy. Soc. (B) 127: 473-487.

Miller, D.C. 1977. Handbook of research design and social measurement. D. McKay, New York.

Mizuno, T., and H. Tsuji. 1974. Harboring behavior of three species of cockroaches, Periplaneta americana, P. japonica, and Blattella germanica. Jap. J. Sanit. Zool. 24: 237-240.

Moore, W. S., and T. A. Granovsky. 1983. Laboratory comparisons of sticky traps to detect and control five species of cockroaches (Orthoptera: Blattidae and Blattellidae). J. Econ. Entomol. 76: 845-849.

Muesebeck, C. F. W., K. V. Krombein, and H. K. Townes. 1951. Hymenoptera of America North of Mexico. Synoptic Catalogue. U.S.D.A. Mono. No. 2.

Narasimham, A.U. 1984. Comparative studies on Tetrastichus hagenowii (Ratzeburg) and T. asthenogmus (Waterston), two primary parasites of cockroach oothecae, and on their hyperparasite Tetrastichus sp. (T. miser (Nees) group) (Hymenoptera: Eulophidae). Bull. Ent. Res. 74: 175-189.

Nixon, J. 1984. Cockroaches and rodents make life tough when you're talking trash. Pest Control 52(9): 33, 37-38.

Olkowski, W. 1974. A model ecosystem management program. Proc. Tall Timbers Conf. Ecol. Anim. Control Habitat Manage. 5: 103-117.

Piper, G. L., R. R. Fleet, G. W. Frankie, and R. E. Frisbie. 1975. Controlling cockroaches without synthetic organic insecticides. Texas A & M Univ. Ext. Pub. L-1373. 4 pp.

Piper, G. L., G. W. Frankie, and J. Loehr. 1978. Incidence of cockroach egg parasites in urban environments in Texas and Louisiana. Environ. Entomol. 7: 289-293.

Princis, K. 1954. Wo ist die urheimat von Blatta orientalis L. zu suchen? Opusc. Ent. 19: 202-204.

Pul'ver, K. Yu. 1973. Dissemination of synanthropic cockroaches and their migration in some districts of a city. Med. Parazitol. Parazit. Bolezni. 42: 103-104.

Rau, P. 1924. The biology of the roach, Blatta orientalis Linn. Trans. St. Louis Acad. Sci. 25: 57-79.

-------- 1943. How the cockroach deposits its egg case; a study in insect behavior. Ann. Entomol. Soc. Am. 36: 221-226.

Ravlin, F. W., and W. H Robinson. 1985. Audience for residential turf grass pest management programs. Bull. Entomol. Soc. Am. 31(3): 45-50.

Rehn, J. A. G. 1945. Man's uninvited fellow traveler - the cockroach. Sci. Monthly 61: 265-276.

Richards, A. G., and M. N. Smith. 1955. Infection of cockroaches with herpomyces (Laboulbeniales). I. Life history studies. Biol. Bull. 108: 206-218.

Robinson, W. H and P. A. Zungoli. 1985. Integrated control program for German cockroaches (Dictyoptera: Blattellidae) in multiple-unit dwellings. J. Econ. Entomol. 78: 595-598.

Rose, B. 1982. Lizard home ranges: methodology and functions. J. Herpetol. 16: 253-269.

Roth, L. M., and E. R. Willis. 1954. The biology of the cockroach egg parasite, Tetrastichus hagenowii (Hymenoptera: Eulophidae). Trans. Am. Entomol. Soc. 80: 53-77.

-------- 1956. Parthenogenesis in cockroaches. Ann. Entomol. Soc. Am. 49: 195-204.

-------- 1957. The medical and veterinary importance of cockroaches. Smithsonian Misc. Collect. 134: 1-147.

-------- 1960. The biotic associations of cockroaches. Smithson. Misc. Coll. 141: 1-439.

Runstrom, E. S., and G. W. Bennett. 1984. Movement of German cockroaches (Orthoptera: Blattellidae) as influenced by structural features of low-income apartments. J. Econ. Entomol. 77: 407-411.

SAS. 1982a. SAS User's Guide: Basics. SAS Institute Inc., Cary, N.C.

SAS. 1982b. SAS User's guide: Statistics. SAS Institute Inc., Cary, N.C.

Schoof, H. F., and R. E. Siverly. 1954. The occurrence and movement of Periplaneta americana (L.) within an urban sewerage system. Am. J. Trop. Med. Hyg. 3: 367-371.

Seelinger, G. 1984. Sex-specific activity patterns in Periplaneta americana and their relation to mate-finding. Z. Tierpsychol. 65: 309-326.

Shuyler, H. R. 1956. Are German and Oriental roaches changing their habits? Pest Control 24(9): 9-10.

Silverman, J. 1986. Adult German cockroach (Orthoptera: Blattellidae) feeding and drinking behavior as a function of density and harborage-to-resource distance. Environ. Entomol. 15: 198-204.

Slater, A.J. 1984. Biological control of the brownbanded cockroach, Supella longipalpa (Serville) with an encyrtid wasp, Comperia merceti (Compere). Pest Manage. 3(4): 14-17.

Slater, A.J., M.J. Hurlbert, and V.R. Lewis. 1980. Biological control of brownbanded cockroaches. Ca. Agricul. 34: 16-18.

Slominski, J. W., and W. L. Gojmerac. 1972. The effect of surfaces on the activity of insecticides. Univ. Wisconsin Research Report 2376.

Solomon, M. E., and B. E. Adamson. 1955. The powers of survival of storage and domestic pests under winter conditions in Britain. Bull. Ent. Res. 46: 311-355.

Tarry, D. W., and M. Lucas. 1977. Persistance of some livestock viruses in the cockroach Blatta orientalis. Ent. Exp. & Appl. 22: 200-202.

Thoms, E. 1985. Survey format influences evaluating public attitudes toward arthropods. Proc. Entomol. Soc. Wash. 87: 875-883.

Townes, H. 1949. The nearctic species of Evaniidae (Hymenoptera). Proc. U.S.N.M. 99: 525-539.

Tsuji, H., and T. Mizuno. 1973. Effects of low temperature on the survival and development of four species of cockroaches, Blattella germanica, Periplaneta americana, P. fuliginosa, and P. japonica. Jap. J. Sanit. Zool. 23: 185-194.

Tucker, J. B. 1984. Exterior perimeter treatment: reducing the insect reservoir. Whitmire Pest Manage. Quarterly 3(2): 4-5.

Usman, S. 1949. Some observations on the biology of Tetrastichus hagenowii, Ratz. - an egg parasite of the house cockroach (Periplaneta americana, L.). Curr. Sci. 11: 407-408.

Vargas, M. V., and F. B. Fallas. 1974. Notes on the biology of Tetrastichus hagenowii (Hymenoptera: Eulophidae) a parasite of cockroach oothecae. Ent. News 85: 23-26.

Velsicol Chemical Corp. 1982. Improving your profit picture. Systema Corp., Chicago, Ill. 72 pp.

Webb, J. E. 1961. Resistance of some species of cockroaches to organic insecticides in Germany and France, 1956-59. J. Econ. Entomol. 54: 805-806.

Wen-qing, L. J. N. 1984. Bionomics of Tetrastichus hagenowii parasitizing the oothecae of Periplaneta fuliginosa. Acta Entomol. Sinica 27: 406-409.

Willis, E. R., and N. Lewis. 1957. The longevity of starved cockroaches. J. Econ. Entomol. 50: 438-440.

Willis, E. R., G. R. Riser, and L. M. Roth. 1958. Observations on the reproduction and development in cockroaches. Ann. Entomol. Soc. Am. 51: 53-69.

Wood, F. E. 1980. Cockroach control in public housing. Pest Control 48(6): 14-16, 18.

Wood, F. E., W. H Robinson, S. K. Kraft, and P. A. Zungoli. 1981. Survey of attitudes and knowledge of public housing residents toward cockroaches. Bull. Entomol. Soc. Am. 27(1): 9-13.

Wright, C. G. 1965. Identification and occurrence of cockroaches in dwellings and business establishments in North Carolina. J. Econ. Entomol. 58: 1032-1033.

-------- 1979. Survey confirms correlation between sanitation and cockroach populations. Pest Control 47(9): 28.

Zabinski, J. 1929. The growth of blackbeetles and of cockroaches on artificial and on incomplete diets. Part I. Br. J. Exp. Biol. 6: 360-386.

Zungoli, P.A. 1982. Aspects of dispersal and population structure of Blattella germanica (L.) in field habitats and attitudes concerning aesthetic injury levels. Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Va.

Zungoli, P. A., and W. H Robinson. 1984. Feasibility of establishing an aesthetic injury level for German cockroach pest management programs. Environ. Entomol. 13: 1453-1458.

PUBLICATION STATUS OF DISSERTATION

Chapter 2:

Thoms, Ellen M., and William H Robinson. 1986. Distribution, seasonal abundance, and pest status of the oriental cockroach (Orthoptera: Blattidae) and an evaniid wasp (Hymenoptera: Evaniidae) in urban apartments. J. Econ. Entomol. 79: 431-436.

Chapter 3:

Thoms, E. M., and W. H Robinson. 1986. Distribution and movement of the oriental cockroach (Orthoptera: Blattidae) around urban apartments. (in preparation for submission to Environ. Entomol.)

Chapter 4:

Thoms, E. M., and W. H Robinson. 1986. Insecticide and structural modification strategies for the management of oriental cockroach (Orthoptera: Blattidae) populations. (submitted to J. Econ. Entomol.)

Chapter 5:

Thoms, E. M., and W. H Robinson. 1986. Potential of the cockroach oothecal parasite Prosevania punctata (Hymenoptera: Evaniidae) as a biological control agent for the oriental cockroach (Orthoptera: Blattidae). (submitted to Environ. Entomol.)

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