Proceedings of the National Conference on Urban Entomology 1986

Compiled By: PATRICIA A. ZUNGOLI

Department of Entomology
Clemson University

These proceedings, the tangible results of the 1986 National Conference on Urban Entomology, are dedicated to Walter Ebeling and James M. Grayson, pioneer urban entomologists, whose work and leadership inspired this generation of entomologists and particularly the participants of the conference.

NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

Planning Committee

Gary W. Bennett
Department of Entomology
Purdue University
Lafayette, IN 47907

Philip J. Hamman
Department of Entomology
Texas A & M University
College Station, TX 77843

George W. Rambo
National Pest Control Association
8100 Oak Street
Dunn Loring, VA 22027

William H Robinson
Department of Entomology
Virginia Polytechnic Institute
and State University
Blacksburg, VA 24061

Michael K. Rust
Department of Entomology
University of California
Riverside, CA 92521

Claude Thomas
B & G Equipment Co.
P.O. Box 130
Plumsteadville, PA 18949

F. Eugene Wood
Department of Entomology
University of Maryland
College Park, MD 20742

Patricia Zungoli, Comm. Chair.
Department of Entomology
Clemson University
Clemson, SC 29634-0365

PREFACE

Barely a year has passed since the planning committee first sat down to begin discussing what form a national conference on urban entomology should take, but certainly the seeds were planted long ago. Foremost among those responsible for our reaching this point are Drs. Walter Ebeling and James Grayson. These men were pioneers in urban entomology. We dedicate this conference to both of them and in their honor we will continue the pursuit of excellence in teaching, extension, and research that has been their hallmark.

As a committee, our first order of business was to agree on the goals and objectives for the first effort. We agreed that our objective was simply "to foster interest and activity in the area of urban entomology among university, government, and industry personnel through information exchange." We hoped that a national conference would open channels of communication to encourage greater collaboration among those of us working in this area of entomology. Our goal was to gain an identity for the research being conducted in the area of urban entomology. We hoped that a national conference would gain recognition from administrators and funding agencies - from those individuals who hold within their power our ability to expand our teaching, extension, and research efforts.

We felt that the scope of the conference had to be broad enough to benefit a wide range of interests and needs without trying to encompass the whole. We felt that the focus of the first conference should be research. Whether we spend our time at teaching, extension or research we need to be aware of new information in our specific areas. We felt that using this conference to synthesize the research data that is available would be of benefit to everyone.

Finally, we felt it essential that we encourage participation by all workers in urban entomology whether representatives of universities, industry or government. We saw a national conference as an opportunity for us to learn together, to share our perspectives, and to lay a plan for future achievements.

Urban entomology is an endeavor whose time has come. There were over 200 people registered for the Conference to attest to that fact. We came collectively because we shared a common interest. The fact that we came at all makes a statement about the direction that urban entomology is headed. The time has come for us to take responsibility for the development of our discipline. We need basic and applied research that we can turn into sound pest management and pest control programs. It is critical, especially now, when the entire country is faced with severe budget cuts for us to have a plan. We need to join forces, to organize, to present a strong united front to gain support for our programs. We need to communicate and cooperate to build new innovative programs that will bear the burden of competing with agricultural research programs for the small amount of funding that is available. The challenge is there to be taken. We, all of us, must take responsibility for meeting that challenge. If we are to continue to grow in a positive direction we must consciously plan to steer the course of our pursuits.

We are still a relatively small group. That puts us in an excellent position to establish a network of communication that will enable us to build a solid foundation that can move us successfully into the next century. The foundation must be laid with care, and forethought of the responsibilities we will have, to better serve a world whose population will be approaching seven billion by the year 2000. All aspects of urban entomology - research, teaching, and extension - will flourish out of need to meet the demand of our ever-growing human population. It is up to us to see to it that it flourishes well. We hope that this first National Conference on Urban Entomology served as a vehicle for organization. It is not mandatory for urban entomologists to collaborate on projects, (although it would be refreshing), but it is essential that we communicate the knowledge that we have available. There is no time to waste over-lapping our efforts. We realize the importance of urban entomology and now many others recognize it too.

Patricia Zungoli, Chairman
National Conference on Urban Entomology

TABLE OF CONTENTS

A PERSPECTIVE OF URBAN ENTOMOLOGY

William H Robinson
Department of Entomology
Virginia Polytechnic Institute and State Univ.
Blacksburg, VA 24061

Introduction

In the past ten years urban entomology has developed into one of the most dynamic and important disciplines in the science of entomology. From the offices of a few extension entomologists, who served a clientele often overlooked by traditional extension programs, urban entomology has grown to include many industry- and university-based research and teaching faculty across the U.S. This group of young entomologists conducts applied and basic research on insect pests that affect the largest target audience on earth--modern man living in urban and industrial environments. They have formed a discipline with a described audience, a growing body of knowledge, one or two textbooks, and a genuine jargon. Indeed, urban entomologists can talk to each other about the feasibility of establishing aesthetic injury levels (Zungoli and Robinson 1984), resistance profiles, focus apartments (Akers and Robinson 1981), spray patterns, and decision theory (Mumford and Norton 1984). Although slow to start, urban entomology has certainly arrived!

The chemical industry associated with this discipline has followed a similar evolution. While agriculture markets have flattened or even faltered, industry has recognized the size, value, and importance of urban entomology's target audience. In the last few years several of the large companies have developed new products, reorganized their technical staff, or given increased emphasis to their pest control or speciality products divisions. Of course, to do this they have hired some of the best young, urban entomologists. The fluctuating and uncertainity of the agriculture markets in the next few years will only lead to further investment in pest control, and in the pest control service business. As a result of this, urban entomologists will continue to find research and development challenges in business and industry.

The continued growth of this discipline is as certain as the continued urbanization of the world's population, and the need for prevention or control of insects affecting the health and home of man. The quality of the science in the discipline will grow with financial support, academic recognition, and the continued exchange of information and ideas. The objectives of this paper are to present my perspectives on the quality of the discipline, and to give some prospectives on the future of urban entomology on the occasion of our first national conference.

Urbanization of the world and the U.S.

The target audience for urban entomology is man--in his house and other structures, whether in single units or gathered together in large numbers to form towns, cities, or metropolitan areas. The world population is approximately 4.5 billion--and growing (Freedman and Berelson 1974). A large percentage of this population lives in large metropolitan areas--whether in a developed or developing country (Vining 1982). Indeed, modern man lives in an urbanized society. He has taken a portion of the natural and agricultural environments and completely altered them to form a completely new environment--the anthropobiocoenosis, the human environment. Into this urbanized environment he has brought or encouraged a select group of vertebrates and invertebrates, and many of these are now pests in and around his house and other structures (Povolny' 1971).

The majority of future population increases will be in the Third World or developing countries. Modern agriculture is endeavoring to feed the growing numbers in these countries, but success and the prospects for success are limited. The most pressing demographic problem in the Third World is not the rapid population growth, but the increasing concentration of the population in the major cities. The large cities may cover a considerable portion of the national territory, and be the nerve center of the nation. In addition to containing much of the country's industry and urban population, the cities are generally the seat of the national government. Because of the significance of the cities, disruption there can threaten the stability of the entire nation. Throughout the Third World rapid population growth in metropolitan areas is having a disruptive effect. Some of the large cities in developing nations are so crowded and polluted that it appears they have reached the limit of the carrying capacity of their environment. Rapid population growth in the cities creates a demand for housing, sanitation, and pest control that can strain the budget of a developing country (Vining 1985).

More than 76% of the U. S. population now lives in urban areas. A recent report from the U.S. Bureau of the Census (1984) stated that the growth spurt of rural or nonmetropolitan areas that marked the 1970s has slowed considerably. About 90% of the population increase since 1980 has occurred in the Sun Belt areas of the South and West. The 50 fastest growing metropolitan areas in the 1980s are all located in the South and West. In the Northeast, where the metropolitan population declined in the 1970s, metropolitan areas are clearly growing again. In the Midwest, population growth in metropolitan areas has slowed perceptibly since 1980. The two fastest-growing metropolitan areas with populations of 1 million or more are in Texas--Houston-Galveston-Brazoli and Dallas-Fort Worth, with increases of 15% form 1980 to 1984.

The Bureau of the Census (1983) reported that central cities are growing more than they did in the 1970's. Only seven of the 23 central cities with populations above 500,000 in 1984 are estimated to have lost population since 1980. In the Northeast and Midwest, central cities as a group lost a large share of their population from 1970 to 1980. Six central cities that lost population in the 1970's have reversed that trend in the 80s: Boston, New York, Indianapolis, Denver, New Orleans, and San Francisco.

Clearly, urban entomologists have a mandate from the urbanized and uneven distribution of the U. S. population. Our potential audience is large--consisting of about 180 million people, and is centered in the north and southeast, close to the offices and laboratories of many university-based urban entomologists. There are 86.8 million households, but only 58% are composed of married couples--20.6 million Americans now live by themselves.

There has been a significant decrease in family size--from an average 3.14 people in 1970 to 2.69 in 1985. This trend will translate into more apartment and condominium living by younger americans. In those apartments and houses will be the 98 million dogs and cats maintained as pets in the U.S.

Strength of the Research Base

Urban entomology must be able to respond to the needs of it's target audience with useful research data and effective control programs. The ability to respond will depend on the depth and strength of the research available for the most frequent urban insect pests. The status of some pests in the urban environment may change on a regional or seasonal basis, but there are some that remain consistent. These include cockroaches, fleas, yellowjackets, termites, powderpost beetles, old house borer, and carpenter ants (Hilburn et al. 1984, Klass and Carroll 1984); all impact on the home, health, or food of man. Designing strategies for the prevention, control, or elimination of these pests depends on the availability of information on their biology and habits.

The USDA- and university-based entomologists are two of the most important contributors to the research base for urban entomology. Within each of these groups are scientists working on the biology and control of some of the most important pests. The USDA effort is divided between the Wood Products Laboratory at Gulfport, MS, and the Man and Animals Laboratory at Gainsville, FL. Those in academia are located in entomology departments in about 15 universities across the U.S.

At the USDA Wood Products Laboratory the major effort is evaluating termite control materials, incuding insecticides, baits, and biological control materials. In addition to termites, this is the only laboratory in the U.S. that conducts research on the biology and control of powderpost beetles. In spite of the economic importance of termites and powderpost beetles in the U.S., the Federal support for research on this group is only 5.0 scientist years.

The research at the Man and Animals Laboratory in Gainsville, Fl is centered around cockroaches and fleas. In spite of the importance of these household pests, there is only a small amount of research time available--approximately 3.0 scientist years. One area of research emphasis at the laboratory is evaluating insecticide efficacy and resistance in the German cockroach, and the cat flea. The research on the cat flea is valuable because there are few locations in the U.S. conducting such work.

Perhaps not all the insects I have selected as important can be studied by USDA entomologists. However, they all have significant impact on the people and structures in the urban environment. Perhaps some of the 210 projects, 95 scientist years, and $14.5 million devoted to tobacco could be diverted to research on household cockroaches and fleas; or perhaps some of the 1165 projects, 449 scientist years, and $64 million devoted to deciduous fruit nuts could be diverted to research on yellowjackets, carpenter ants, or other social Hymenoptera pests in the urban environment.

University-based entomologists working on household and/or structural insects are usually located at a Land Grant University as a part of the

Agricultural Experiment Station. The benefits to being associated with the Experiment Station are apparently few. Based on Cooperative State Research Service data for 1984, only approximately $64,000 were shared with 10 universities (nearly half of the funds went to 2 of them) for research on insects that might be considered urban pests. Nevertheless, there is a considerable amount of research conducted by university-based entomologists, primarily on funds provided by the chemical or pest control industry.

Cockroaches. (6 scientist years, 12 institutions). This is one of the best researched group of urban pests. This may be be due to the relative ease of rearing and studying cockroaches, and the opportunity to receive commercial support to conduct research. While there is a need for research on household cockroaches, there is a greater need to take some of the information we already have and design some control programs.

Fleas. (2 scientist years, 3 institutions). Fleas are not easy to rear and not easy to study in the field. Consequently, fleas are not studied much at the university level. This is most unfortunate, as fleas are serious household pests throughout the U.S.

Yellowjackets. (0.75 scientist years, 2 institutions). The number of university-based entomologists working on yellowjackets is not equal to their importance. These and other stinging hymenopterans are common in urban and suburban areas. An unpublished survey conducted in 1982 showed that yellowjackets were responsible for 54% of all the "wasp" stings in an urban area in Virginia.

Termites. (8 scientist years, 6 institutions). There are nearly eight scientist years devoted to termites. While the number seems adequate, it should be noted that there is little or no research being conducted in the northeastern states. There is need for more research on the biology and control of the Formosan termite.

Powderpost beetles, old house borer. (0.15 scientist years, 1 institution). These wood-infesting insects are economically important throughout most of the south and eastern U.S. However, there is little research being conducted on their biology and control. It is difficult to maintain colonies of these pests.

Carpenter ants. (0.5 scientist years, 2 institutions). Although I show one half of a scientist year devoted to these pests, there is no active research being conducted at this time. A few entomologists have devoted research time to these pests, but are now working on other insects because of lack of research funds.

Clearly, the research base for urban entomology is inappropiately small and poorly funded. There are insect pests of the urban environment that receive little or no research, so that programs for managment or control can not be developed. The university-based scientist is the key component in the research base, yet the poorest served by Federal and state funding. The university researcher can recruit and train future scientists to work in the urban environment; the university researcher can develop the interdisciplinary research and knowledge essential for new technology; and the university researcher can interact with extension specialists, industry, and professional pest control operators to bring about innovations and make them applicable to the urban audience.

Economic Impact of Urban Insect Pests

Household and structural insects pests have a significant impact on the quality of life in the urban environment. Indeed, man may perceive insects as pests because they are violating the "sacred space" of the home (Eliade 1959). However, the most significant--and measurable--impact insects have may be in the amount of money spent on their control. The severity of a pest problem may be measured by assessing how much money is spent in attempts to alleviate or eliminate the problem.

Cockroaches directly affect more people in the U.S. than any other group of arthropods. Of the five or six cockroach species associated with man, the German cockroach is the most prevalent household pest. While the impact of this insect on the quality of life is significant, the cost of controlling it may be the most important. The cost can be very high; for example, the cost for pest control (materials, equipment, and labor) in the New York City Housing Authority is approximately $2.6 million per year. Redevelopment and Housing Authorities in northeastern U.S. spend an average of $8.60 per housing unit for cockroach control, and the total dollars spent is approximately $36 million (Robinson and Zungoli, unpublished data).

The average monthly charge by professional pest control operators in the Northeast for German cockroach control was $33.60. Zungoli and Robinson (unpublished data) estimate that for the year 1981 the total revenue received by pest control companies in the northeastern U.S., specifically for German cockroach control, was $42.1 million. In Georgia alone, the estimated losses due to German cockroaches was $16.7 million (Nolan and Brady 1985). Homeowners spend approximately $340-million-a-year on ant and cockroach control aerosols. Pesticide use by homeowners consumes approximately 150 million cans and traps per year (Anonymous 1985).

The cat flea is becoming as serious a household pest as the German cockroach. The use of insecticides to control household flea infestations has increased in the last few years. Dodson and Robinson (1986) estimated that professional pest control operators and veterinarians in Virginia collected $2.5 million dollars for household flea control in 1983. Nolan and Brady (1985) reported the estimated losses and control costs for household fleas in Georgia to be over $8 million.

Shelter is the largest item contributing to the total cost-of-living in the U.S., and accounts for over 29% of the factors involved in calculating the Consumer Price Index. In the U.S. in 1985 approximately 236 million people lived in over 86 million housing units, of which 56 million were single family structures (Bureau of the Census 1983). The damage due to termites in the U.S. is estimated to be $750 million dollars (EPA 1983). Although there are no national data for losses due to powderpost beetles, losses in eleven southeastern states were estimated to be over $12 million (Williams and Smythe 1979).

Old house borer and carpenter ant damage to structures is not well documented. However, these insects can be as serious a pest as termites in some areas of the U.S. and Canada. In Georgia the losses and control costs for these two pests is estimated to be over $4 million (Nolan and Brady 1985).

The data available for the economic impact of urban insect pests is not complete, and scattered throughout several sources. However, the message is clear--the dollars spent on the prevention or control of household and structural insect pest control are substantial, and certainly equal those in agriculture.

I think we would increase the amount of Federal and state support, and recognition from academic administrators for urban entomology if we could document the economic importance of the professional pest control industry, and household and structural insect pests.

Summary

The target audience of urban entomology research and control programs is large, and growing. It includes not only the people in urban and rural areas, but the professionals in industry and pest control services that augment, adapt, and adopt research to better fit their needs and their audience. When considered as a whole, the urban entomologist can have a beneficial impact on the health and well-being of a large portion of the world's population. The impact of urban pests, such as cockroaches, termites, and fleas, on the health and economy of the target audience is significant. When measured in the amount of pesticide purchased by homemakers for use in and around the house, the economics quickly begin to indicate the potential health hazard to this untrained user group.

Understanding the economic and psychological impact pests have on the target audience is essential to designing control programs. Effective programs can reduce or eliminate the interaction of man and pest, and they can reduce or improve the use of pesticides in the home environment. However, program designers must consider the perceptions of the audience, as well as the incidence of the pest when measuring the success of a program.

The research base for the science of urban entomology is not adequate for the work required. Federal officials are quick to encourage university-based scientists to obtain funds from segments of the user audience--the chemical industry, and the professional pest control operator. In fact, these groups do support urban entomology research. The National Pest Control Association and state pest control associations from Virginia, Maryland, South Carolina, Kentucky, Indiana, and others are actively supporting university-based research programs. It is time for Federal and state support to increase commensurate to the need and the audience.

Prospectives of Urban Entomology

I have not watched and participated in the emergence and early growth of urban entomology without having some thoughts about its future. As my concluding comments, I would like to offer some of my prospectives of urban entomology.

PROSPECTIVE #1. We should bring a global view to the research and teaching program in urban entomology. Clearly, the developed and many of the developing countries of the world are urbanized. There are scientists around the world working on household cockroaches, fleas, wood-infesting insects, and other urban pests. We already share in many of the pest species; let's begin to share more of the research data and the resulting pest managment or control programs.

Although there are differences in culture and society structure--human response to household pests are very similar. Regardless of whether you live in an apartment in Hangzhou, China or Roanoke, VA--cockroaches are not welcome in your home--and for many of the same reasons (Robinson, unpublished data). What we learn about education programs and control strategies in the United States can be applied to programs around the world.

I encourage the future Conference Steering Committee to consider inviting researchers from England, Europe, Canada, Japan, China, and Central and South America to present data and participate in the next Conference of Urban Entomology.

PROSPECTIVE #2. We should devote more reserach to the technology of applying pesticides in the household environment. Pest control professionals apply over 23 million pounds of pesticides (active ingredient) in and around homes in the U. S. (Brandt and Zarow 1985). While there has been some valuable research conducted on determining pesticide drift in household environments, there has been little work on reducing that drift once it is known.

Basic and applied research on pests in the home, or the urban environment in general, involve the target audience, the target pest, and the most effective control strategies. We should expand that traditional line of reasoning and consider how any pesticide will be delivered to the target substrate, how much will reach that substrate, and how much will reach non-target substrates. Pesticide use in the agricultural environment is well known, well documented, and well publicized. As the agriculture/urban interface increases, the problems of pesticide drift will attract more attention. Pesticide use in the home, by professionals and homeowners, is little known--and is a sleeping giant (Taylor 1985).

PROSPECTIVE #3. In addition to expanding our traditional research programs to include the delivery of pesticides to the target substrate, I think we should devote more work to designing and delivering pest managment or control programs. Too often our research is isolated to a few narrow aspects of a pest. There are few who are willing to gather up the collected facts and from them design a program that can be used by homeowners or professional pest control operators. We must have scientists that will collect and synthesize information from many sources, and make of it something useful.

Research in urban entomology is often difficult because it must be conducted more in the field--houses and apartment--and less in the laboratory. Conditions in the field are often not conducive to the replication and control available in the laboratory. However, urban entomologists should not limit their work to only the subjects that can be studied rigorously. To do that would neglect a great deal of the interesting and useful aspects of our discipline, and deprive us of information on how the target audience and target pest interact.

PROSPECTIVE #4. The most critical need for urban entomology is financial support and academic recognition to increase and/or expand the teaching/research/extension base of the discipline. The present research base is not commensurate with the size and needs of the target audience. Support for agricultural research has been our strongest competitor, Agriculture has a strong contingent at the Federal level, but all that may be changing soon. Perhaps a sign of the weakening of agriculture's position is the position the present Administration has taken toward the Cooperative Extension Service when it came to suggestions for trimming the Federal budget.

Urban entomology has the largest--albiet unorganized--target audience for any program. The key word is unorganized, because we probably can never change the unorganization at the audience level. However, we can organize at the academic, industrial, and commercial level into a force that can lobby the appropiate agencies for support.

I suggest the formation of an Urban Entomology Working Group. I suggest that representatives from industry, commercial pest control, NPCA, and academia form a small working group that will serve together toward the goal of gaining and increasing support for all aspects of urban entomology. Goals for this group would include, 1) meeting with the Environmental Protection Agency to emphasize the importance of household and structural pesticides, 2) meeting with the USDA and EPA to emphasize the need for research funds for urban entomology, 3) meeting with academic official to empahsize the importance of urban entomology, and 4) generate and/or collate information on the economic importance of urban insect pests and pest control programs.

Clearly, there is much that can be done by a coalition of all segments of this discipline. We are not likely to organize our target audience, but we can organize ourselves. Today, we have taken the first step toward that organization.

Acknowledgment

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PEST MANAGEMENT STRATEGIES AND INSECTICIDE RESISTANCE

Frederick W. Plapp, Jr.
Entomology Department
Texas A&M University
College Station, Texas 77843

Introduction

Use of the modern synthetic organic insecticides has provided us with a powerful tool for controlling insects. But in an important sense, the system is self-destructive. The more insects we kill, the faster they may respond. That is, successful chemical control of an insect is all too often followed by the development of resistance. What this means is that the less insecticide we use, the longer insecticides will last.

This fact should not surprise us. It is a basic tenet of biology that the greater the selection pressure applied to an animal population, the faster it will evolve. The surprising thing is the speed at which this has happened. We started exposing insects some 40 years ago to classes of chemicals totally different from those to which they had been in contact with previously. Yet, the insects responded rapidly to these hitherto unknown materials. How did they do it and why? Were there pre-existing mechanisms available and if so, why were they there? What were they doing in the absence of insecticides?

Experience has taught us quite a bit about which insects are likely to develop resistance and if they do, which type of resistance will occur. The likelihood is related to diet. Thus, broad spectrum omnivores like German cockroaches have the capacity to develop metabolic resistance to insecticides. Blood feeders such as fleas lack this capability. They are more likely to develop target site resistance. Finally, consider the termites. These are so specialized in many ways including choice of diet that they seem to totally lack the ability to develop resistance.

In the past resistance has often been treated as a black box, a mysterious and infinitely complex problem which is beyond our ability to solve. Not so. The genetic basis of resistance is usually quite straightforward and not that difficult to understand. So too, is the biochemistry of resistance. The overall hypothesis I wish to present is that once an adequate understanding of these factors is achieved, it should be possible for us to devise solutions to many problems of insect control associated with resistance development.

So, today, I bring you an optimistic message. Resistance, I will try to show, is a comprehensible problem, one that is very interesting in biological terms and also, one that in many cases is subject to resolution given an adequate understanding.

The Genetics of Resistance

There are probably at least 100 different insecticides to which resistance is known to occur. The important question is, how many genes for resistance are there? Are there many genes, each conferring resistance to one or only a few insecticides? Or, are there only a few genes each conferring resistance to multiple insecticides?

The question has enormous practical implications. The answer largely determines how we approach the problem of resistance. If there are multiple genes for resistance and each confers resistance to one or ony a few insecticides, a practical solution is obvious. We could switch. Resistance would be solved by replacing one chemical with another. We could then use each chemical in turn until resistance develops, and then replace it with a new one. In theory, the rotation could go on forever and the process could provide a permanent resolution of the problem.

The alternative answer is that there are only a few genes for resistance. If this is true, then cross-resistance associated with each gene would be widespread, extending to all chemicals with the same mode of action or to all chemicals metabolized by the same enzymatic process. In this case resistance would be present even to chemicals never before used for insect control.

Experience has taught us that this second alternative, few genes, each with a broad spectrum of resistance associated with it, is the usual situation. It follows, therefore, that switching to a new chemical, at least to one closely related to existing toxicants, will not solve the problem.

Thus, resistance can't be solved by switching. Rather, we have to carefully define and determine the nature of resistance associated with each gene. Once that is done, it should be possible to develop solutions. Among those I shall propose are the use of synergists to block metabolic resistance the use of oils to increase rates of uptake, and the use of combinations of chemicals to confound the metabolic enzymes or modify the responses at target sites.

Biochemical Mechanisms of Resistance

There are only a few basic types of responses that insects have utilized in the process of becoming resistant to insecticides. A brief summary of these mechanisms follows:

Behavioral Resistance A very important resistance mechanism involves change in behavior. The most famous example concerns malaria mosquitoes and DDT (Muirhead-Thompson 1960). Evidence has been obtained that mosquitoes avoided DDT by flying outside to rest and digest after taking a blood meal rather than resting on the walls of treated habitations.

Two recent articles (Gould 1984, Lockwood et al. 1984) have reviewed behavioral resistance. Both concluded that behavioral resistance is widespread and that changes in behavior are frequently present in combination with other resistance mechanisms.

Behavioral resistance is certainly important in urban entomology and may be considered both positive and negative aspects. That is, insecticide avoidance may yield control by driving insects away from a treated area. Alternatively, behavioral resistance may make control more difficult by reducing contact time to such an extent that the insects may not pick up enough toxicant to cause mortality.

How does behavioral resistance work? Almost certainly increased in activity of receptors that recognize the toxicant is the reason. In other words, resistant insects may be by per-sensitive and thereby escape pesticides and never get lethal doses.

Physiological Resistance More common as resistance mechanisms - or at least more widely studied - are what we can describe as physiological or biochemical resistance. As far as is known there are 3 basic types. These are decreased rate of uptake, increased rate of detoxification, and finally, change at the target site.

Decreased rate of uptake as a resistance mechanism seems to be very widespread in insects. By itself the mechanism confers only low levels of resistance, 5-fold or less in the case of the house fly for example. However, when combined with other resistance genes, the effect of a gene for decreased rate of uptake may be to multiply by 5-fold the level of resistance associated with other mechanisms.

Increased rate of metabolism is the major resistance mechanism for soft or biodegradible insecticides such as organophosphates and carbamates. A variety of enzymatic processes, mixed-function oxidases, esterases, and glutathione transferases, to name a few are involved. Earlier research described metabolic resistance as a wondrously complex process. More recent data from our laboratory have indicated that a single genetic change is always present in metabolic resistance, regardless of the particular enzyme involved (Plapp 1984). The product of this gene seems to be a protein which recognizes insecticides and initiates the induction of the necessary detoxifying enzymes. Thus, a regulatory step rather than the enzymes themselves seems to be of major importance.

Finally, when other mechanisms fail, insects sometime develop resistance by means of changes at target sites. This approach has been most important with hard-to-metabolize insecticides such as DDT and cyclodienes and now, with the synthetic pyrethroids. Target site resistance to these insecticides has been hard to work with because for many years we did not know their mode of action. If you don't know why something is toxic you can't work very well with changes at the target site. Recent data indicate these insecticides act by binding to receptor proteins on nerve membranes which are involved in transmission of nerve impulses. Resistance seems to involve changes in numbers, apparently a decrease in number, of the target receptors. What happens is that the decrease appears to make it harder or the insecticide to find the receptors. It's sort of a needle-in the haystack approach.

Solutions to the Resistance Problem

A main point to remember is that there appear to be only a few mechanisms of resistance. Since the number is small it should be possible to elucidate the reasons why and then, develop solutions to resolve the problem.

A second point to remember is that the use of insecticides for a long period of time or at high dosages is eventually self-defeating. The insects respond and become resistant. Therefore, the best long term management program for insecticides involves minimum usage in combination with maximum utilization of non-chemical strategies.

Behavioral resistance is a largely undescribed type of resistance in terms of mechanism. In experiments done recently we tried to determine if oils combined with insecticides might act to block the avoidance resistance mechanism known to be present in cockroaches. To our surprise we found that oils were just as repellent to cockroaches as were insecticides. Thus, if repellency is the goal it may be possible to produce such effects with oil sprays without using any toxic chemicals at all. Similar findings with oils and pest insects on cotton give credence to this idea.

Another effect of oils is that they may block resistance associated with decreased rate of insecticide uptake. Again, data on this idea are best known from field research. Toxaphene was used many years in combination with DDT or methyl parathion for boll weevil or Heliothis control on cotton. The available evidence indicates its main effect may have been to facilitate insecticide uptake. I think it likely that most oil additives work by this mechanism.

Metabolic resistance can frequently be blocked by combining synergists with insecticides. The best known of these chemicals are the methylenedioxyphenyl compounds such as piperonyl butoxide. When combined with carbamate insecticides against resistant cockroaches, piperonyl butoxide dramatically increases toxicity. This suggests that the resistance mechanism must involve increased ability to detoxify insecticides oxidatively. This is the mechanism in house flies, at least, and it is probably the same in cockroaches. Actually, the first use of synergists was with the very easily metabolized insecticide pyrethrum. This material is so biodegradible that even susceptible insects have a high natural tolerance to it. Piperonyl butoxide dramatically reduces this tolerance and to this day is routinely used in increase the toxicity of pyrethrum to susceptible insects.

Another approach that deserves further investigation is the use of insecticide mixtures. Frequently, when two drugs are mixed their toxicity is more than expected. This is often becuase one chemical interferes with the metabolism of another. Thus, pyrethrum:diazinon combinations are widely used for household insect control. Another approach is to mix more closely related insecticides. Frequently, two organophosphates are used in combination. For years EPN was used as a synergist for methyl parathion against pests of cotton. From our own work we know that certain organophosphates with plus and minus isomers, those with four substituetns attached to the phosphorus atom, are synergistic in combination with other insecticides. In our own lab we have shown that profenofos synergizes methyl parathion. Safrotin^{R} or propetamphos, an insecticide registered for codkroach control, is quite similar in structure to profenofos. Like profenofos it should act synergistically when combined with other phosphates such as malathion, diazinon or chlorpyrifos for cockroach control.

Another possible way to overcome metabolic resistance involves the idea that a single major gene product, a receptor protein, plays a central role in this phenomenon. Based on current work in our laboratory, the receptor appears to function by recognizing insecticides, binding them, and initiating trascription of DNA leading to the sythesis of appropriate detoxifying enzymes. If receptor agonists that bind to the protein better than insecticides do could be found, they might act to confound the insect's defense system and prevent induction of appropriate detoxifying enzymes. Such a chemical might act both to overcome resistance already present and also, prevent the development of resistance in the first place. It is possible that the synergist DEF (tributyl phosphorotrithioate) works in this way. The demonstration by Ranasinghe and Georghiou (1979) that DEF blocked resistance to temephos in the mosquito *Culex pipiens fatigans* points in this direction.

The final major problem area involves target site resistance. Here too, the results or agricultural research may be instructive. For example, target site resistance to DDT or pyrethroids in *Heliothis* pests of cotton is largely overcome by the use of the formamidine miticide chlordimeform in combination with insecticides. The precise mechanism is not known, but clearly involves effects at the target site (Chang and Plapp, 1983).

Summary

Briefly, I have tried to show in this paper that the number of mechanisms responsible for resistance to insecticides are few in number. Once these are under stood it may be possible to develop solutions to many resistance problems. Among the approaches that look promising are use of oils only, oil-insecticides combinations, insecticide:synergist combinations and combinations of insecticides. The latter can be used to block both metabolic resistance and possibly, some types of target site resistance as well. Much more remains to be done, however, before these ideas will be useful in practiced terms for resistance management.

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INSECTICIDE RESIDUES

James B. Ballard
Dow Chemical U.S.A.
505 S. Lenola Road
Moorestown, NJ 08057

Unspecified residues in the food supply were reported as the primary concern of consumers according to a recent Food Marketing Institute survey (Anonymous 1985c). The results of a risk-ranking survey conducted by Decision Research indicated that pesticides were ranked 28th out of 30 in actual cause of death in the United States. Business and professional people ranked pesticides 15th, the League of Woman Voters ranked them 9th, and college students ranked them 4th (Anonymous 1985b).

Pest control operators (PCO's) were exposed to some degree to the insecticides they apply in the course of their work (Heath and Spittler 1985 and Mix 1986). Attempts to measure actual exposure of PCO's has not revealed undue risk of chronic disease (Anonymous 1979a, Heath and Spittler 1983). Changes in cancer mortality and incidence rates for all non-respiratory sites, including the liver, have been unremarkable even though the liver is the site usually associated with carcinogenic molecules (Gibbons, 1982).

Insecticide residues could be defined as 'the quantity of a specific insecticide found at a specific location within a structure at a specific point in time'. In most instances, insecticide residues would be located on or in various surfaces or contained within the air of the structure. The relationship between insecticide residues and the occupants of the structure is largely unknown and is the source of anxiety in the public perception of risk.

The objective of this review was to assess the ecology of residues generated through the application of insecticides in the management of insect populations in urban structures. For the purposes of this discussion, only molecules from the Organochlorine (OC), Organophosphate (OP), Carbamate (C), and Synthetic Pyrethroid (SP) classes of insecticide will be included.

General Parameters

Since quantities of insecticides can be measured in the parts per trillion range, the use of insecticides to manage urban insect populations should be expected to occasionally result in residues; both at the point of application (target) and in other untreated locations (off-target) within the structure (Wright and Jackson 1971, Leidy et al 1982, Wright et al 1984a and Wright et al 1984b). The magnitude of residues found on untreated surfaces within a structure could be influenced by the application technique (fogging, spraying, painting, crack and crevices) and the pest management strategy utilized (monthly, weekly treatments) (Gold et al 1981, Wright and Jackson 1974, Ballard and Gold 1982 and Ballard et al 1984). Analysis of uncovered food present during crack and crevice treatments revealed very low levels (0.25 ppm) of insecticide residues (Bennett 1976, Jackson and Wright 1975, and Dishburger et al 1978) and below the Acceptable Daily Intake (ADI) for the food tested.

The length of time an insecticide residue can be detected within a structure is dependent upon a number of treatment variables such as: insecticide used, formulation, concentration applied, volume applied, time since application, application technique, area treated, air exchange rate of structure, sampling and analytical method, and the microclimate within the structure. Degradation pathways such as volatility, hydrolysis, adsorption and UV light also influence the degradation rate or ecology of the insecticide molecule. This template of treatment variables overlies and strongly influences the degradation pathways which eventually result in the destruction of the molecule.

Insecticide residues decompose or disappear according to the law of 'first-order kinetics' in that the rate of disappearance is related to the amount deposited. In reality, only the initial phase follows this law with later residues disappearing at a rate dependent upon the amount of interference from other variables (substrate, adsorption) (Matsumura 1975).

Sampling, Analysis, and Interpretation

One of the greatest challenges in dealing with insecticide residues is the determination of how to sample a substrate, choose a viable analytical technique, identify the molecules collected, and interpret the results. Unfortunately, a single standard method for the collection and analysis of residue samples does not exist. Two EPA publications (Watts 1980, 1981) contain an overview of many sampling and analytical methodologies. Chromosorb[R] 102 sorbent air sampling tubes have proven to be a reliable trap device for most insecticides used in urban structures (Thomas and Nishioka 1985 and Atallah 1985). Airborne residue sampling using other trap materials have also been evaluated (Melcher et al 1978, Wright and Leidy 1982 and Yeboah and Kilgore 1984). Residue levels in air may be compared to National Academy of Sciences (NAS) suggested interim guideline values which are:

chlorpyrifos	10 ug/m^3
chlordane	5
heptachlor	2
aldrin	1
dieldrin	1

These guidelines were designed to provide safe levels of termiticide which could be present in the air of living areas of treated homes and inhaled by humans for 24 hour continuous life time exposure. Other guidelines which apply to applicators would include those adopted by the American Conference of Governmental Industrial Hygienist and listed as Threshold Limit Values (TLV) or Short Term Exposure Limits (STEL).

Some representative 40 hour work week exposures (TLV) would include:

diazinon	100 ug/m^3
chlorpyrifos	200
chlordane	500
propoxur	500
malathion	10000

In the case of substrate or surface samples, no sampling or exposure guidelines exist. Surface sample results could perhaps be compared to food residue tolerances to aid in interpretation, however, residues on food would represent oral exposure while residues on structural surfaces represent largely dermal exposure. Dermal LD_{50} values are usually substantially greater than oral LD_{50} values.

The primary consideration in the procuring of air or surface samples is the determination of the quantity of an insecticide molecule in terms of a known amount of air sampled or surface area wiped.

Organochlorines

During World War II the use of inorganic insecticides, especially those based on arsenic, was largely supplanted by DDT. Though less toxic and more effective than inorganics, neither DDT nor its metabolites degrade very rapidly. Coupled with high fat solubility, it was later determined that DDT and related compounds were readily stored in human adipose tissue (Spindler 1983). DDT and its metabolites are still detectable in human tissue and in house dust though at levels in the ppb range and below no-effects levels (ADI 0.05 mg/kg/day) (Spindler 1983 and Starr et al 1974). The presence of other OC's (dieldrin, lindane, heptachlor, aldrin, chlordane, and heptachlor) in human tissue has also been reported (Spindler 1983, Reiner et al 1977, Bloomer et al 1977, and Pollock and Kilgore 1978).

Some representative OC's would include:

OC	PPM water solubility	volatility x 1 million	oral LD_{50} rats	dermal LD_{50} rats
DDT	0.0012	0.15	87	1931
dieldrin	insol.	0.18	40	65
chlordane	insol.	10.00	283	580
aldrin	0.0100	6.00	39	65
heptachlor	insol.	300.00	40	119
lindane	7.3000	9.40	76	500

*values from Ware (1978) or cited literature

Degradation pathways of OC's would include: volatility, adsorption, and light activated mechanisms. Hydrolysis in water could be important in some instances however most OC's are practically insoluble (1 ppm) in water. High energy or light activated dehalogenation or oxidation would be of more importance (Matsumura and Murti 1982). Physical factors such as substrate treated, air exchange rate, and volatility could play an important role in the regulation of OC molecules available for degradation. The rate under which these processes operate in the home is unknown.

That most of these stable molecules are actually mixtures of isomers complicates the analysis because of multiple gas chromatography peaks and large numbers of stable metabolites (Pollock and Kilgore 1978 and Goebel et al 1982). In addition, the degradation of each isomer may occur at different rates (Goebel et al 1982).

Of recent concern are the air-borne residues of OC's resulting from their use as termiticides (chlordane, aldrin, heptachlor and dieldrin). Used as termiticides, these molecules persist in the soil under homes from 11 to 34 years depending upon the molecule (Anonymous d 1983 and Bennett et al 1974). Because of the large reservoir of molecules injected beneath a structure, air monitoring has been used to measure air-borne residues which are then compared to the NAS guideline air levels. It was reported that air-borne residues in 57 of 3956 homes exceeded the NAS guideline (Anonymous e 1983) while Wright et al (1985) reported 3 of 60 homes contained air residues in excess of the guideline. Wright and Leidy (1982) also reported the air-borne residues in label-treated homes occasionally exceeded the guideline and that chlordane and heptachlor were found on carpet swatches placed in homes after treatment with these termiticides.

Organophosphates

OP insecticides were developed and marketed at about the same time as the OC's. While the OP molecules tend to be generally more toxic in short term effects upon target organisms, the molecules are short lived and not lipophilic (Mulla et al 1981).

Representative OP's would include:

OP	ADI*	PPM water solubility	volatility x 1 million	oral LD_{50} rats	dermal LD_{50} rats
chlorpyrifos	.0015	2	18.70	97	2000
diazinon	.0020	40	140.00	66	379
malathion	.0200	145	40.00	885	4000
dichlorvos	.0040	10,000	12,000.00	25	59
acephate		650,000	1.70	866	2000
propetamphos		110	81.00	119	474

*Acceptable daily intake in mg/kg for man (Vettorazzi 1976)

Many of the OP's are characterized by either a high water solubility (hydrolysis) or a high volatility. Dichlorvos, which has both characteristics, disappears rapidly from the surface of plant tissue via volatility with the remaining residue hydrolyzed into inactive metabolites. Residues were also destroyed by normal washing and cooking activities (Vettorazzi 1976). Gold et al (1984) reported an average of 67% reduction in dichlorvos air residues 24 hours after application to cockroach infested structures. Dichlorvos was also found to hydrolyze in the presence of moisture (Miles et al 1962).

Malathion, with its high LD50, is commonly utilized both in agriculture and in urban pest control. Its degradation rate is rapid with commercial food processing resulting in more than a 90% residue reduction on vegetables (Vettorazzi 1976). The influence of the substrate treated upon the volatility of malathion was observed when 100% reduction in Cryptolestes ferrugineus (Stephens) populations was achieved in grain above treated galvanized-steel surfaces after 8 months while only 50% reduction was noted on treated plywood (White and Abramson 1984 and Tauthong and Watters 1978).

Other factors which influence surface residues involve various coatings or surface abrasion/cleaning techniques. Generally, surface disruption increases surface activity (Mensah and Watters 1981) while coating a porous surface tends to increase volatility from that surface (Burkholder and Dicke 1966). The smoother the surface (or coating) the more volatility and the less residue left through time (Snetsinger 1984, Wright and Leidy 1980).

Degradation pathways for OP's, in addition to volatility, would include photodecomposition. The half life for chlorpyrifos on an inert surface was 3.2 days (photodecomposition) and 0.3 days (volatility) (Meikle et al 1983).

The use of chlorpyrifos as a termiticide has not resulted in the violation of the NAS guideline of 10.00 ug/m^3 (Vaccaro 1984). The low (10.00 ug/m^3) airborne residues probably occur because of the rapid degradation of the molecule in air and upon surfaces within the structure.

Carbamates

General awareness of OC persistence in the environment eventually led to the development and use of less persistent yet efficacious insecticide molecules. By the 1960's C's have begun to replace some uses of OC's (Ratagopal et al 1984). Representative C's would include:

C	ADI*	PPM water solubility	volatility x 1 million	oral LD_{50} rats	dermal LD_{50} rats
propoxur	.02	2000	6.50	95	1000
bendiocarb		40	5.00	143	4000
carbaryl	.01	40	40.00	307	2000

*Acceptable daily intake in mg/kg for man (Vettorazzi 1976).

Degradation of C and OP residues can usually be discussed in terms of weeks or months rather than in months and years as with the OC's. Hydrolysis appears to be a major pathway for the degradation of carbaryl with increased rates (in days) when moisture, high temperature, or light are included (Rajagopal et al 1984). A build-up of stable carbaryl metabolites has also been reported to occur in soil (Rajagopal et al 1984). Under dry conditions in a structure it may be more likely that volatilized molecules undergo photooxidation or else hydrolyze with airborne moisture.

Synthetic Pyrethroids

SP's are synthetic molecules produced to duplicate or improve upon the active agents (phyrethrins) found in naturally produced pyrethrum. The highly volatile pyrethrins (Pyrethrin I and II, Cinerin I and II, and Jasmolin I and II) readily oxidize in air (Meister 1985). Representative SP's would include:

synthetic pyrethroid	PPM water solubility	volatility x 1 million	oral LD_{50} rats	dermal LD_{50} rats
pyrethrum	insol.		200	1,800
allethrin	insol.		680	11,200
resmethrin	insol.	2,580,000.00	1,500	3,040
permethrin	1.00	1.00	2,000	4,000
cypermethrin	0.700	0.90	251	4,900
fenvalerate	0.002	0.28	451	1,000

*values from cited literature, pyrethrum included for comparison.

Early SP's (allethrin, resmethrin) were unstable in air and light thus restricted in use to within structures. Newer SP's, developed since 1973, are more toxic to mammals but more stable in air and light (Mourkidou, 1983). Like OC's, the SP's consist of a mixture of isomers. Coupled with incomplete information of metabolites, long column retention, and the thermal instability of some pyrethroids, the use of high precision liquid chromatography is required in the analysis of these molecules (Mourkidou, 1983).

Efficacy of the same SP insecticide can vary in that each different synthesis methodology of the insecticide can result in a different ratios of isomers. Two permethrin products currently (Feb. 1986) labeled for termite control vary in their isomer mixtures (Torpedo[R] cis 35%, trans 65%, and Dragnet TC[R] cis 55%, trans 45%). A difference in activity between these two termiticides may be detectable as the cis isomer is twice as active as the trans isomer (Holden 1979). The isomers found in the resulting product are not only different in activity, but also in residue degradation (Winney 1973, Mourkidou 1983, Chapman et al 1981, Holden 1979, and Yoshioka 1978).

Persistence of residues of both permethrin and cypermethrin for two to three months, measured in terms of German cockroach mortality of at least 50%, was demonstrated in the laboratory (Bennett et al 1984) and in structures (Ballard and Gold 1984). Permethrin was reported as an effective protectant for six months when applied to woolen cloth and challenged with Dermestes sp. (Bry et al 1979).

Degradation pathways of SP's are largely oxidation (cis) and hydrolysis (trans) (Mourkidou 1983 and Chapman et al 1981).

Photodecomposition is rapid (2 hours) for early SP's such as resmethrin (technical info. sheet, Penick Corp.). Photodehalogenation and photooxidation have also been known to occur in SP's but at unknown rates within structures (Matsumura and Murti 1982).

Residue Reduction

As air-borne residues arise from molecules escaping from residues on surfaces within or under a structure, the reduction of surface residues will result in the reduction of air-borne residues. Monitoring air-borne residues is often used to monitor the progress of surface residue reduction efforts (Kerr 1984) and the resulting air-borne levels used to determine when to cease clean-up activities by comparing air-borne levels to the NAS guidelines (kerr 1984).

For OC's, physical removal of the residue from the surface using hot water and detergent (aldrin Recommendations for Safe Handling and Use, 1984) or hot water, 10% isopropyl alcohol, and detergent (chlordane, A Residue Management Guide for Professional PCO's, 1984) will maximize residue reduction. Applications of various coatings (polyurethane, polyvinyl alcohol, or silicone) are also recommended to seal OC residues to surfaces but the eventual bleed-through of the OC's has not been addressed.

Physical removal of residues from fabrics is the primary mechanism involved in laundering procedures. In a laundering study involving 11 insecticides, OC's were found to be the most difficult to remove followed by OP and then C insecticides (Keaschall 1984). Laundering fabric using a pre-rinse, hot water, and heavy duty liquid detergent removed at least 75% of any of the 11 insecticides tested. Use of pre-wash spray-on cleaners (Shout[R], Spray 'n Wash[R]) prior to laundering removed at least 90% of the 11 insecticides tested (Keaschall 1984). Emulsifiable concentrates of the OP methyl parathion were found to be more difficult to remove than wettable powder or encapsulated formulations (Easley et al). Pre-treatment of fabric with a soil repellant fluorocarbon finish (Scotchgard[R]) also substantially reduces residue penetration of fabric (Fotos 1984). Regardless of the procedure utilized, laundering will still leave some detectable residues in fabric (Keaschall 1984, Pollock and Kilgore 1978).

The actual destruction of an insecticide molecule on the surface is an approach which could be explored with OP's and C's. In general, basic conditions create higher rates of residue hydrolysis than acid hydrolysis. Additives which increase the solubility of the molecule in water have been found to increase the rate of hydrolysis (Munnecke 1979). The use of oxidizing agents such as chlorine, hydrogen peroxide, ozone or UV light have not been promising. Deactivation of the OP chlorpyrifos on concrete surfaces has been accomplished through the use of the hydrolyzing and oxidizing agent sodium hypochlorite (5.25% household bleach) (Dow Chemical Odor Reduction and Deactivation 1983 and Zungoli 1986 unpublished information).

Physical removal of synthetic pyrethroids using hot water and detergent is recommended in permethrin Technical Information Sheets. Residue levels remaining on surfaces are unknown.

What Does It All Mean

Compared to agriculture, the amount of insecticides used to control structural pests is minor with chlordane, diazinon, chlorpyrifos, malathion and carbaryl the most commonly used (Russell 1983). Insecticides are applied in the home not only by PCO's but also by most homeowners as well (Kamble et al 1982, and Bennett et al 1983). In addition to insecticide residues, offgassing of air-borne non-insecticide residues in new, air-tight structures has been receiving increased attention (Taylor et al 1984, Acierno 1985). Careless handling of cleaners in food handling establishments has also contributed to structural residues (Anderson 1985).

There are changes occurring in the pest control industry which should result in even less insecticide residue in the home through time. The industry is shifting towards crack and crevice applications which would reduce the quantity of residues generated through routine baseboard sprays. The use of OC's in homes has been drastically reduced over the years so that insecticides used in the home today are less persistent than those used previously. New formulations, such as encapsulated insecticides, provide the residual needed to manage pest populations but at the same time reduce airborne residues when compared to conventional formulations. Although training and certification programs have made pest control operators more knowledgeable and efficient, there is still much room for improvement.

Dealing with chemical residues in the home is a rather new phenomenon which has received more attention as our ability to detect lower and lower residue levels continues to improve (Dunn 1980). Earlier legislation, based upon past analytical techniques, discussed residue levels as though zero residue was an obtainable goal. The use of insecticides in homes can result in detectable residues, both on and off target. Current data suggests that these residues are and will continue to be largely trivial in nature.

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THE FORMOSAN SUBTERRANEAN TERMITE, COPTOTERMES FORMOSANUS (ISOPTERA: RHINOTERMITIDAE), IN THE UNITED STATES: 1907 - 1985

Nan-Yao Su and Rudolf H. Scheffrahn
Ft. Lauderdale Research and Education Center
University of Florida, IFAS
3205 College Ave.
Ft. Lauderdale, FL 33314

History and Distribution

The earliest collection of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, in the United States is credited to R. C. L. Perkins who deposited insect specimens collected in 1907 at the Bishop Museum in Honolulu, Hawaii (Swezey 1914). Swezey (1914) later confirmed some termites from Perkins' Hawaiian material as *C. formosanus*. Early on, Ehrhorn (1915) and Crawford (1919) had reported on damage caused by *C. formosanus* on the island of Oahu (Honolulu). Later, *C. formosanus* was collected on the islands of Hawaii (Hilo), Kauai, and Lanai (Fullaway 1925, 1929, and 1931, respectively). Currently, this termite is established on Oahu, Hawaii, Kauai, Maui, and Molokai.

The first confirmed *C. formosanus* infestation in the continental U.S. was discovered in Houston, Texas, in 1965 (Beal 1967). This infestation was reportedly destroyed by fumigation. One year later, *C. formosanus* was reported from nearby Galveston, Texas, and also in New Orleans and Lake Charles, Louisiana (Beal 1967). In 1967, this termite was found in Charleston, South Carolina (Fig. 1). The Charleston specimen, however, was apparently collected in 1957 (C. G. Wright, personal communication). All of these infestations were found near shipyards in port cities, indicating a maritime mode of introduction for *C. formosanus*. The severe damage observed in these areas caused great concern over the threat posed by this termite. A survey of 10 city blocks in New Orleans showed that ca. 5% of homes, ca. 4% of living trees in residential yards, and ca. 9% of the municipal trees lining sidewalks were infested by *C. formosanus* (Spink 1967). This termite was also found attacking lumber piles, aging railroad ties, and utility poles. The initial urgent demands for control by alarmed citizens (Beal and Stauffer 1967) eventually subsided partially due to the perceived slow-spreading nature of this termite.

Although public interest may have diminished, studies on the basic biology and methods of control of *C. formosanus* have been conducted in several research institutions. Information concerning the efficacy of soil termiticides (Beal 1971, Beal and Smith 1971) antitermitic properties of various wood species (Smythe and Carter 1970, Bultman et al. 1979, 1982, Carter et al. 1981, 1983) and novel control concepts using insect growth regulators, IGRs (Haverty and Howard 1979, Haverty 1979a,b, Jones 1984), has been generated at the Southern Forest Experiment Station of the U.S. Department of Agriculture (USDA) Forest Service in Gulfport, Mississippi. Researchers at Louisiana State University concentrated their efforts on elucidating biological information such as foraging activity (King and Spink 1969), developmental biology (King and Spink 1974, 1975), and feeding dynamics (Su and La Fage 1984a,b, 1986). Biological

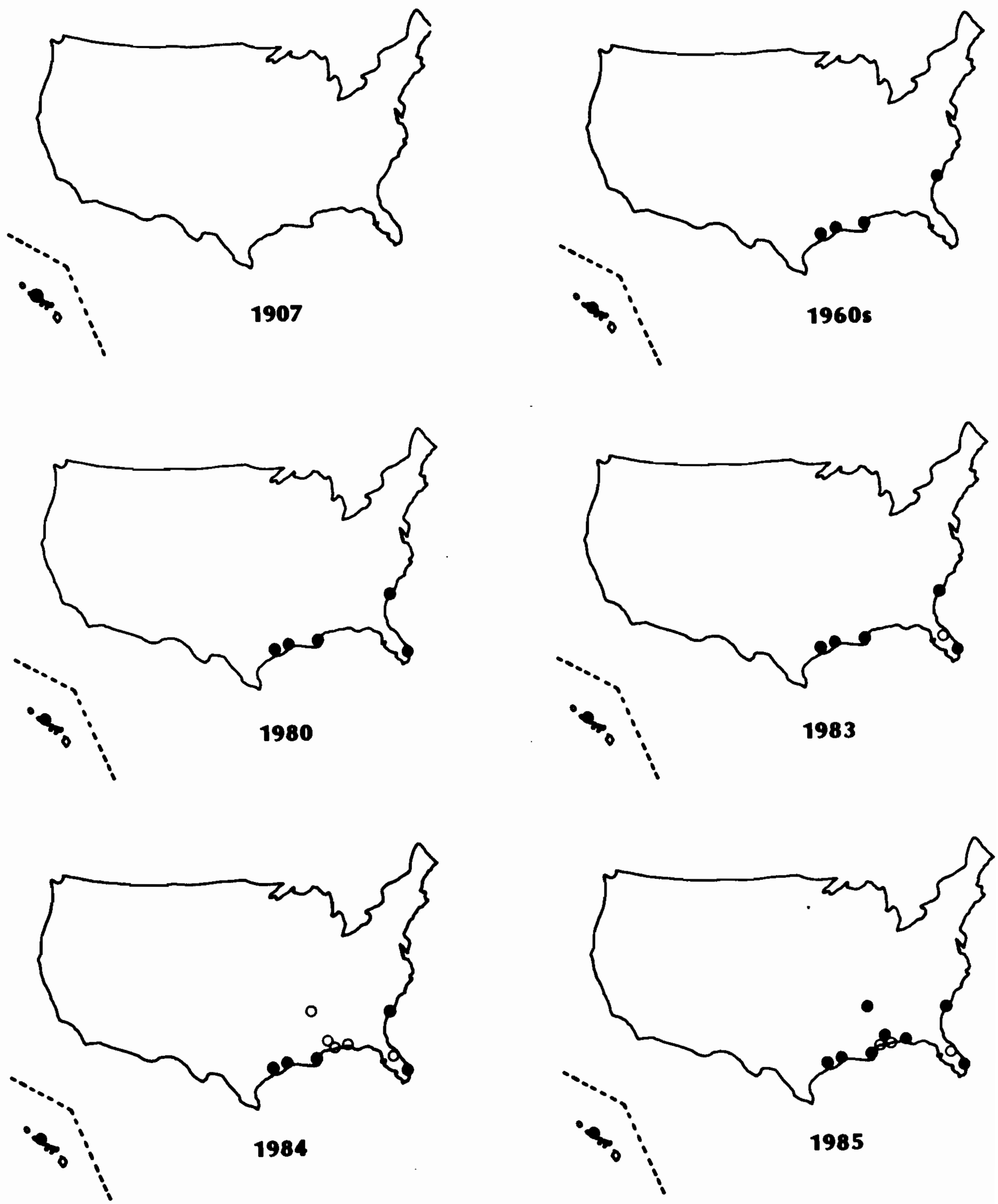

Fig. 1. Distribution of C. formosanus in the United States, 1907-1985. Black circles indicate established infestations. White circles represent finds with uncertain status.

control strategies against *C. formosanus* were investigated at the University of Hawaii where this species is now considered the most destructive insect pest (Leong 1966, Fujii 1975, Lai et al. 1982). Although several microbes were found to be pathogenetic against *C. formosanus*, microbial control of field colonies was unsuccessful (Lai 1977). This failure made evident the lack of knowledge on the basic biology of *C. formosanus* and its interactions with pathogens. This led to the studies of swarming and developmental biology (Higa 1981, Higa and Tamashiro 1983, Leong et al. 1983), and social behavior (Su et al. 1982, 1983, 1984).

When *C. formosanus* was discovered in 1980 in southeastern Florida (Koehler 1980), public interest was again raised (Lewis 1983). The Florida infestations spawned extensive media attention which resulted in heightened awareness and additional finds of this termite in the southeastern U.S. including: Orlando, Florida in 1983, Gulfbreeze, Florida; Mobile, Alabama; Meridian, Mississippi; and Memphis, Tennessee, in 1984 (Fig. 1). Except for Orlando, which was treated in 1984 and Mobile, swarming alates were observed from the above locations during the following year. This termite was thus considered established in these areas. In 1985, one additional infestation surfaced in Biloxi, Mississippi (R. Beal personal communication) which further linked existing *C. formosanus* infestations along the 320 km stretch of Gulf Coast between Gulfbreeze, Florida and Galveston, Texas (Fig. 1).

The rapid increase in *C. formosanus* localities between 1980 and 1985 (seven in five years *vs.* one during 1965-80 and four from 1907 to 1965), however, does not reflect the natural dispersion rate of this termite in the U.S. As the public and pest control industry become more cognizant of the presence of *C. formosanus*, it is expected that more infestations will surface. The often misapplied phrase "rapid spread" (Lewis 1983), therefore, should be replaced by "previously undocumented distribution" of this termite as new locations are found.

Economic Impact

An established colony of *C. formosanus* having 2-3 million individuals (Tamashiro et al. 1980) and a foraging range of up to 100 m in any direction (King and Spink 1969, Li et al. 1976, Lai 1977), may threaten a multitude of wood products within their foraging limits. Records in Hawaii show that *C. formosanus* can cause major structural damage to an unprotected home in 6 months, and almost complete destruction within 2 years (Tamashiro 1984). Studies in Hawaii also found that *C. formosanus* attacks at least 47 species of living plants including sugarcane, avocado, mahogany, banyan, eucalyptus, coconut, citrus, and mango (Lai et al. 1983). The ability of this termite to penetrate through plaster, plastic, asphalt, and soft metal (lead or copper) in search of food and moisture has been observed and described by earlier entomologists (Oshima 1919, Ehrhorn 1934). Their highly publicized ability to chew through or dissolve concrete and metal with the soldiers' "acidulous secretions" (as first speculated by Oshima in 1919 and cited by many) is without any basis in fact.

No accurate survey data is available to assess the current economic impact of this pest on a nationwide basis. In 1966, it was estimated that *C. formosanus* caused ca. $3 million damage per year in Hawaii (Anonymous 1966). Although Beal and Stauffer (1967) discredited this estimate due to inadequate citations, this figure had grown to $15-30 million per year within 10 years (Fujii 1975, Lai 1977, Higa 1981). Based on the amount of termiticides sold in Hawaii, M. Tamashiro (personal communication) estimated the control cost at ca. $50 million in 1984 and ca. $60 million in 1985.

Since December 1985, pest control operators in Louisiana are required to submit detailed reports for termite treatments (La Fage 1986). The reports will be analyzed to predict control costs associated with *C. formosanus* in Louisiana. If similar reporting procedures are adopted in other areas, accurate data on the economic impact of *C. formosanus* should be available in the future.

Current Control Measures

Soil treatment remains the most common practice for protecting structures from ground-borne infestations of *C. formosanus*. The long-term residual insecticides used include chlordane, heptachlor, chlorpyrifos, and to a lesser extent, aldrin. Recently, permethrin was also registered as a soil termiticide. The method of soil application is similar to that used for *Reticulitermes* spp. *C. formosanus*, however, is capable of initiating aerial infestations that maintain no ground connections. A survey conducted in southeastern Florida showed 25% of structural infestations were initiated by alates from roofs of high-rise buildings (Su and Scheffrahn 1986). Aerial infestations can also be formed by within-structure foraging groups separated from a subterranean mother colony, or by a ground colony that moves to an above-ground location in response to more favorable conditions (Tamashiro 1984). The elimination of within-structure moisture buildup, always associated with aerial colonies, precludes the occurrence of such infestations.

Soil treatments are ineffective against aerial infestations. For small structures with restricted aerial infestations where termite activity can be easily detected, physical removal and spot treatment of the infested area is sufficient. In large buildings with extensive infestations where termite activity is difficult to delineate, fumigation with sulfuryl fluoride or methyl bromide has been successfully used. The high moisture content of the *C. formosanus* galleries, however, poses a barrier to these hydrophobic fumigants. Study is underway to determine the relationship between wood and nest material moisture content and fumigant efficacy.

Current Research Activities

There are four research institutes in the U.S. that have contributed to and/or are currently studying the biology and control of *C. formosanus*. The termite project at the University of Hawaii initiated a field evaluation program in 1979 to assess the efficacy of long-term soil termiticides. Currently this project includes six field sites on three islands. Soil samples are collected annually and bioassays are conducted to test the effects of the termiticides, concentrations, and substrates on *C. formosanus*. The Southern Forest Experiment

Station of the USDA Forest Service at Gulfport, Mississippi, is one of the leading institutes in applied termitology and was also involved in documenting the first C. formosanus infestation in the continental U.S. The laboratory is currently screening soil termiticides and compounds to be used in bait blocks such as insect growth regulators (IGRs) and slow-acting toxicants. Field testing of presently registered soil termiticides is currently being conducted by the USDA at a study site on Midway Island. The realization of a bait-toxicant system is the major thrust of termitologists at Louisiana State University. Studies such as fungi-termite-wood relationships, field feeding preconditions, recruitment behavior, ant-termite interactions, and interspecific competition between C. formosanus and Reticulitermes spp. are now underway at LSU.

A preliminary survey of C. formosanus distribution was started in 1981 by the University of Florida Institute of Food and Agricultural Sciences (Thompson 1985a,b). In 1985, a full-scale research project was initiated at Ft. Lauderdale Research and Education Center of the University of Florida. Current research activities include: development of a termite trapping method suitable for urban settings, testing fumigants against C. formosanus, bioassay of antitermitic wood extracts and identification of feeding deterrents, and screening of slow-acting compounds for forager-initiated colony eradication.

Current soil treatment techniques do not eliminate large ground colonies of C. formosanus, therefore, once established in the soil they cannot be eliminated from a new location (Fig. 1). Future studies should address strategies for colony eradication such as use of slow-acting, nonrepellent insecticides or microbes. Only after these techniques are developed and administered to field colonies, can we expect to contain further encroachment by C. formosanus. Another problem in limiting C. formosanus distribution is the lack of effective quarantine measures. After eliminating C. formosanus from a new location, should such technology become available, legislation should be enacted to prevent re-introduction or dissemination.

Because of increased sightings of C. formosanus in the southeastern U.S. in recent years, we propose to establish a coordinating body among entomological research institutes in this area. Such a group of researchers will promote the exchange of accurate information concerning the whereabouts and economic impact of this termite.

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OUTDOOR SPECIES OF COCKROACHES

Arthur G. Appel
Department of Zoology-Entomology
Auburn University
Auburn, AL 36849-4201

Outdoor cockroaches are probably one of the least investigated groups of urban or suburban insect pests. Even though these species present unique opportunities for physiological, behavioral, ecological, and evolutionary studies, little basic or applied information exists for most species. In this paper I will 1, introduce cockroach classification and some of the outdoor species, 2, discuss several areas of basic research in which outdoor cockroaches could be superior experimental subjects, and 3, relate this basic information to truly integrated strategies for control.

McKittrick's (1964) study is the basis for today's cockroach classification system. Morphological characters from such organs as the proventriculus and male and female genitalia, as well as mode of reproduction and oviposition behavior, were used to delineate five families (Fig. 1). Scientifically and economically important outdoor cockroach species are found in each of these five blattarian families. In the most phylogenetically distinct family, Cryptocercidae, the wood eating cockroach, Cryptocercus punctulatus Scudder, has provided valuable insights into the relationship between cockroaches and termites. The rudimentary social structure of this species has also shed light on the development of sociality. Unlike most other cockroaches, members of the family Polyphagidae, like Arenivaga investigata Friauf and Edney, are often found in deserts. Their adaptations to xeric environments include hypopharyngeal pouches, low cuticular permeability to water vapor, and spherical cercal tricobothria used to navigate in sand dunes.

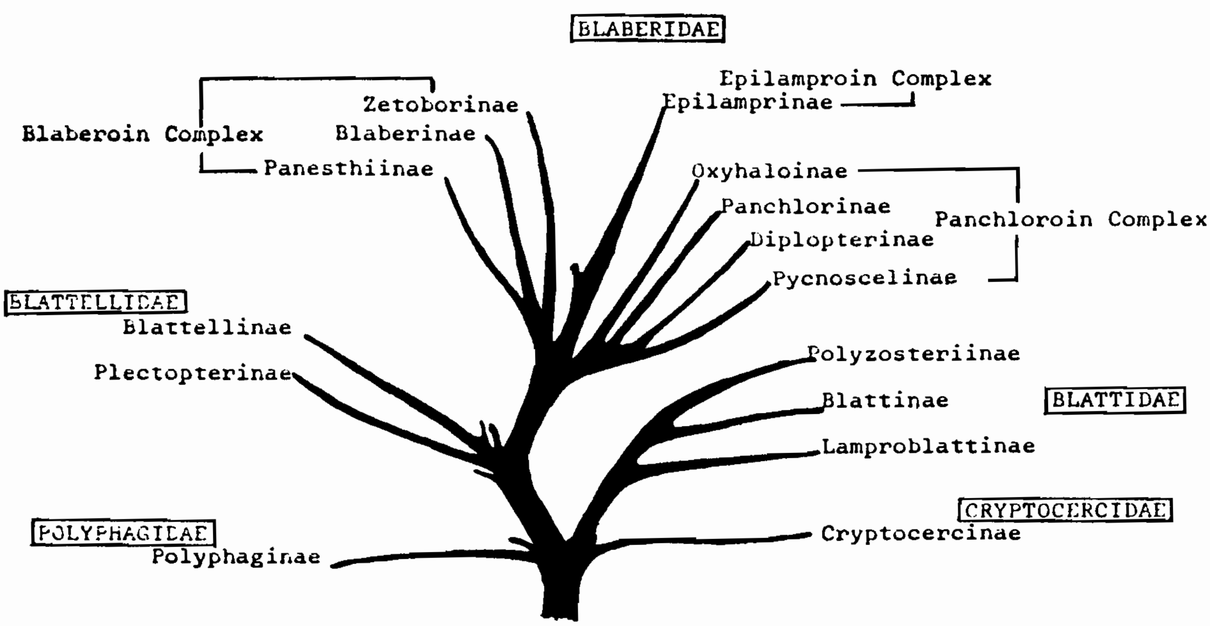

Fig. 1. Phylogram of the families and subfamilies of the Blattaria after McKittrick's "Text Figure 1" (Huber 1974).

The majority of the cockroach literature concerns the biology and control of one indoor species in the family Blattellidae, the ubiquitous German cockroach, Blattella germanica (L.). The courtship and mate-finding behaviors of outdoor members of this family are varied and point to important aspects of behavioral ecology. The Blaberidae possess many derived reproductive features: these cockroaches are ovoviviparous and in one case viviparous. Behavioral studies have shown primitive brood care and agonistic hierarchies. The family Blattidae, specifically the genera Blatta and Periplaneta, has been investigated more than all of the other families of outdoor cockroaches combined. Members of this family have been used for important research in neuropharmacology, neuroethology, water and ion regulation, endocrinology, pheromone mediated behaviors and many other areas. It is noteworthy that most studies on outdoor cockroaches have been concerned with either a specific topic, such as the action of insecticides on nerves, or on the chemical control of a particular species. There are few studies that have utilized the rich and diverse cockroach fauna to investigate broad concepts or to test hypotheses.

The American cockroach, Periplaneta americana (L.), is the best known outdoor cockroach species. Other important members of this genus include the smokybrown, P. fuliginosa (Serville), the brown, P. brunnea Burmeister, the Australian, P. australasiae (F.), and the Japanese cockroach, P. japonica Karny. The closely related genus Blatta contains the oriental cockroach, B. orientalis L., and the recently described B. furcata (Karny) (Bohn 1985). These blattid species are relatively large. Adults range in length from about 3 (B. orientalis) to 8 cm (P. americana), and the adults of all but the two Blatta species can fly. The Florida wood roach, Eurycotis floridana (Walker), is another blattid that is found outdoors in southern Florida and the Neotropics. There are also a number of less well known outdoor cockroach species in the families Blaberidae and Blattellidae. Of the blaberids, the green adult Cuba cockroach, Panchlora nivea (L.), and the Surinam cockroach, Pycnocelus surinamensis (L.) are commonly found in the southeastern U. S. and in Central America. Other blaberids such as the Lobster cockroach, Nauphoeta cinerea (Oliver), the Maderae cockroach, Leucophaea madera (F.), and several Blaberus species are frequently encountered in goods transported from Central and South America. Two blattellid genera, namely Ectobius and Parcoblatta are the common "wood roaches" in Europe and North America, respectively. Both genera contain a number of species that seem to inhabit very similar environmental niches. In addition, there are two "field roaches" in the U. S., B. vaga Hebard, found throughout the Southwest, and B. lituricollis (Walker) from Hawaii. Over 99% of the approximately 3500 cockroach species could be considered outdoor species, but only very few are abundant enough or close enough to man to be considered pests.

The ecology of outdoor cockroaches has been studies primarily with the pest species P. americana, P. fuliginosa, and, most recently, B. orientalis. The behavioral ecology of some tropical species has also been investigated primarily with an emphasis on mate-finding and social interactions (see Schal et al. 1984). Several general themes have emerged from these studies. First, that there is a pronounced intraspecific vertical stratification of the sexes in those species that may utilize volatile sex pheromones for mate-finding (Fig. 2). Adult male P. fuliginosa were found significantly higher above the ground, up to 6 m, than any other stage (Appel and Rust 1986). Similar results have been obtained with other blattids as well as blaberids and blattellids (Schal et al. 1984). Second, outdoor cockroaches typically have limited

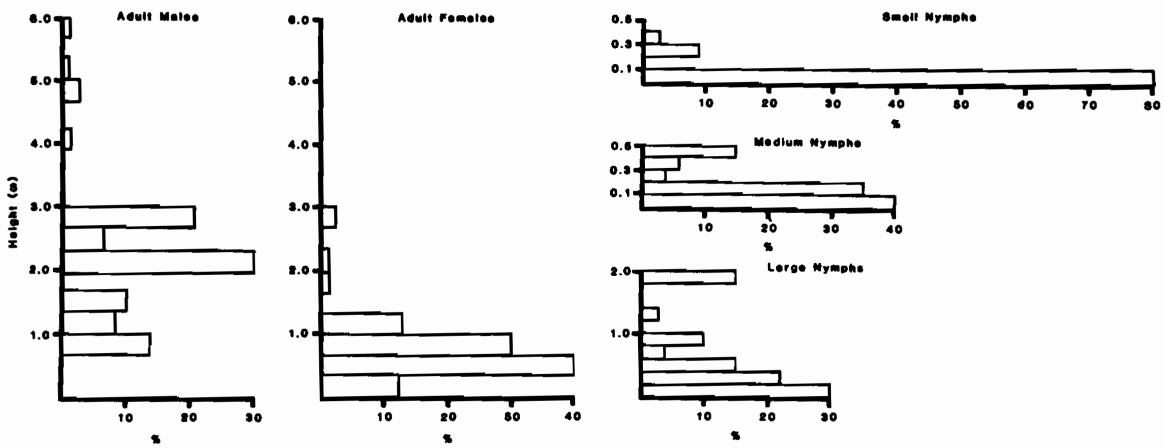

Fig. 2. Percent of P. fuliginosa found at various heights outdoors during the scotophase (Appel and Rust 1986).

movement, resulting in relatively small home ranges. Most individuals in mark-release-recapture studies have been recaptured or observed at or near the site of release. For example, in studies with P. americana in sewer systems (Eads et al. 1954, Haines and Palmer 1955), essentially no movement of cockroaches was detected. Limited P. americana movement, resulting in home range estimates of about $160m^2$, was detected in an urban neighborhood in Texas (Appel 1986). Similarly, movement patterns of P. fuliginosa (Fleet at al. 1978, Appel and Rust 1985) and B. orientalis (E. Thomas, personal communication) are quite restricted. Small percentages of the population of these species, however, dispersed large distances indicating either some differential movement within a population or the presence of vagrants. And third, temperature, relative humidity, and rainfall significantly affect outdoor cockroach movement. Each of these factors (vertical stratification, limited movement, and effects of abiotic factors on movement) have important implications for in-depth population ecology studies as well as for accurately estimating outdoor cockroach population size. Unlike some studies with butterflies, the exact extent of cockroach movement and distribution within their environment has not been characterized, because the entire population has not been marked. Similarly, immigration and emigration rates, and even habitat preference, have not been examined in detail.

Outdoor cockroaches could be valuable experimental organisms in a variety of basic and applied ecological research. For example, the position of cockroaches in urban, suburban, and natural food webs has not been investigated in any detail. In fact, the science of urban ecology is still in its infancy, and ecological studies on cockroaches would greatly increase our understanding in this area. Outdoor cockroaches are usually abundant members of the urban and suburban community structures in tropical and subtropical areas. Since these cockroaches are rather large and are usually easy to work with, basic questions such as community development, energy flux among community members, niche exploitation patterns, species packing, and species diversity could be investigated. Applied studies could benefit control efforts against cockroaches and other omnivorous arthropod pests. Degree-day developmental models could perhaps aid in timing preventative control measures and the identification of predators, parasitoids, and parasites would similarly aid biological control efforts.

Physiological ecology is another area in which outdoor cockroach species are excellent experimental organisms. Several studies have correlated cockroach movement to ambient environmental conditions (Appel and Rust 1985, E.P. Benson personal communication). Physiological limitations, particularly water, contribute to cockroach habitat selection and changes in behavior (A. G. A. unpublished data). Water budgets and the biotic and abiotic factors that affect them are critical to the survival and reproduction of organisms. New techniques, including the use of doubly labeled water, are being used to estimate water and energy flux in a variety of free-living animals. Once the magnitude of influx and efflux is established, both pathways can be further partitioned. For example, in P. fuliginosa, drinking accounts for over 85% of total water influx and cuticular transpiration contributes to over 90% of total water efflux (A. G. A., unpublished data). Although there have been few studies on food selection with cockroaches, when desiccated, other insects and some vertebrates select foods containing more water. Similarly, high energy foods (lipids and carbohydrates) might be required differentially between the sexes, stages or between gravid and non-gravid adult females. Resource limitations and factors that increase resource utilization would alter cockroach foraging patterns. Both basic questions in physiological ecology and species specific physiological requirements can be addressed with outdoor cockroaches.

Behavioral and physiological limitations are reflected in habitat selection and ecology. Harborage selection probably reflects the choice of the least stressful microenvironment. For most cockroaches, photophase harborages should be dark, relatively "safe" from predators, and have constant temperatures and relative humidities. Harborages or preferred resting areas may also be selected for abiotic factors in responses to physiological stress. Out of the harborage, if the availability of free water is severely limited or abiotic conditions increase disiccation, cockroach movement will increase as will home range. Should temperature and relative humidity rapidly change, cockroaches tend to move to habitats similar to which they were acclimated. This is commonly observed during the spring and fall when outdoor cockroaches tend to move indoors in large numbers in response to changing environments.

Successful control of outdoor cockroaches requires proper identification, knowledge of biology and ecology, and a thorough understanding of the use of insecticides. Species that are accidental invaders of homes such as the wood cockroaches (Parcoblatta and Ectobius spp.), the "field cockroaches" (Blattella spp.), and various blaberids must be differentiated from those species that are closely associated with man (Periplaneta and Blatta spp.). Most accidental invasions can be easily avoided by removing or replacing outdoor lighting that can attract cockroaches, by removing brush or debris from around the structure, and by sealing points of access into the structure. Thus, proper identification helps to avoid unnecessary and ineffective insecticide treatments. Identification of pest species is also important since the habits of each species are unique. Following identification, the biology of the species including developmental parameters, physiological limitations, and habitat preference must be considered prior to control efforts. For example, P. fuliginosa is a common outdoor pest throughout the southeastern U. S. and is quite susceptible to desiccation. Infestations of this species in arid locations in southern California are possible only because of the availability of free water from extensive lawn irrigation and because high humidity daytime harborages, like water meter boxes or under rocks and planters, are common. In this example, identification and treatment of harborage sites would be the most efficient strategy. Habitat modification, such as increasing air movement in potential harborage areas to decrease relative humidity, and exclusion by use of screening, caulking, or repellents may also be based on the biology of the pest.

Ecological factors, particularly predators, parasitoids, and parasites may be important naturally occurring outdoor cockroach mortality factors. In studies with P. americana, P. fuliginosa, and B. orientalis the eulophid oothecal parasitoid, Tetrastichus hagenowii (Ratzeburg), parasitized oothecae outdoors at a rate of 20-80% (Roth and Willis 1954, Fleet and Frankie 1975, E. Thoms, personal communication). The ensign wasp, Prosevania punctata (Brulle), also parasitizes B. orientalis oothecae, but only at an 11% rate (E. Thoms, personal communication). Internal parasites such as fungi and protozoa, have also been identified from outdoor cockroaches, but their effects are unknown. The significance of these parasites in maintaining cockroach populations or their potential for decreasing cockroach populations is not known, however, there is a potential for classical biological control.

Chemical control strategies using either repellents or toxicants, must also be based on the biology of the target species. Most outdoor insecticide efficacy studies are severaly flawed because the population sampling method, usually one day trap counts, does not adequately measure the variability in outdoor cockroach population movement. Trapping studies with P. americana and P. fuliginosa have revealed differences in successive daily trap-catches of over 300% (A. G. A., unpublished data). Much of this variation can be explained by considering variations in weather and the effects of trap shyness. Until sampling techniques become more refined, the relative advantages of different toxicants and area wide, barrier, or spot treatments remain speculative.

In conclusion, outdoor cockroaches are both excellent experimental organisms and, in many cases, pests that must be controlled. Basic biological and physiological studies that are important in themselves, are also critical for successful control strategies. With outdoor cockroaches in particular, basic research can reveal both biological principles and with them the basis for control.

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SUBTERRANEAN TERMITES: A PERSONAL PERSPECTIVE

Jeffery P. La Fage

Department of Entomology
Room 402 Life Sciences Building
Louisiana State University Agricultural Center
Baton Rouge, Louisiana 70803

In the preface to his classical treatise on insect morphology, Snodgrass (1935) noted with characteristic understated humor that "The writer of the present text, being convinced that generalizations are more important than mere knowledge of fact, and being somewhat partial to his own way of thinking about insects, has not been able to refrain entirely from presenting the facts of insect anatomy in a way to suggest relations between them that possibly exist only in his own mind."

And so it is with all efforts to bind the past, define the present and predict the future. In the following brief discussion, which attempts to focus on the accomplishments and events embodied in more than one hundred years of termite research in the United States, I have most certainly been guided and constrained more by personal bias than by time or space. For that I make no apologies. Any failure to recognize events and personalities of consequence rests entirely on the shoulders of the author. Finally, by way of introduction, I find it necessary to restrict my remarks primarily to American history despite the fact that much valuable data on the subject have come from foreign laboratories.

In the year, 1860, a paper published by S. H. Scudder on the white ants of America (Scudder 1860) heralded the beginning of termite biology in the United States. While Scudder wrote several additional accounts of termites throughout the remainder of the nineteenth century, his work came to be overshadowed by the outstanding contributions of Nathan Banks at the Museum of Comparative Zoology and Thomas E. Snyder of the USDA Bureau of Entomology who, in 1920, coauthored a revision of the Nearctic termites with notes on their biology and geographic distribution (Banks and Snyder 1920). This landmark publication was the first comprehensive treatment of the taxonomy and biology of the American termites and was to have a profound influence on future workers in the field. Although Banks did not publish extensively on termites after 1920, his influence was, nonetheless, great. Snyder, on the other hand, wrote extensively on the subject and became the undisputed dean of the early American termite biologists. In a career beginning in 1909 and spanning almost six decades, he published nearly 200 scholarly accounts of termite biology including a catalog of the termites of the world (1949), a widely used bibliography (1956, 1961, 1968), and many useful articles on control of both a popular and scientific bent.

The first American to write extensively on the subject of termite evolution and social behavior was Alfred E. Emerson. Long associated with the University of Chicago and the American Museum of Natural History, Emerson amassed one of the largest collections of termites in the world and became well recognized for his scientific accomplishments even beyond the termite community. At about the same time in California, Professor S. F. Light of the University of California began a long career of investigations on the biology and taxonomy of termites of the western United States and Mexico.

Pioneering investigations on the subject of termite physiology were begun by Dr. L. R. Cleveland working at the Museum of Comparative Zoology (MCZ) at Harvard University. He provided much of our basic understanding of the termite-protozoan symbiosis.

By 1928, the destructive capabilities of termites had come to be appreciated by the public. In California, the "Pacific Coast Committee on Termite Investigations" composed of academic and industrial members and advised by Emerson and Snyder, compiled an extraordinarily complete treatise on termite biology and control which was published in 1934 (Kofoid *et al*.). This book stands today as a compendium of useful information on the termites of the United States and is our most complete historical account of termite control in the years before synthetic organic pesticides.

In spite of the fact that ground treatments were being used widely by commercial termite control companies in southern California (Randall and Doody 1934), no single chemical had been discovered which could be considered an adequate preventative or remedial treatment for subterranean termites. In 1934, Sodium arsenite (10% aqueous solution) was being sprayed on the ground under homes to control subterranean termites. It was very toxic to humans, killed vegetation and didn't do a particularly good job of controlling termites (Snyder 1935).

In a book titled, "Our Enemy the Termite" Snyder (1935) provided the first major work on termites directed primarily toward the homeowner. Here he stated, "An experience of forty years in termite control by federal entomologists indicates that radical reconstruction of the foundations is the only permanent and effective remedy for buildings which, usually because of original faulty construction, have become heavily infested [by termites]. Such remedial measures as spraying or fumigation, or even removal of the worst infested timbers, without other protection, are at best temporary."

Snyder (1935) goes on to describe the costs of repairing a "home purchased on the installment plan by a young married couple, living on a salary. Repairs to shut off the subterranean termites from the earth, were estimated to cost five hundred dollars." Putting things in perspective, we note that the first issue of "Exterminators Log" (now "Pest Control") distributed in January, 1933, ran an advertisement by the Hotel Baltimore for $2 rooms (Kerr 1983).

Later that year, in October, the National Association of Exterminators and Fumigators (name later changed to the National Pest Control Association) was established in Washington D.C.

Additional contributions to the termite research literature during this period included an elegant series of papers by R. E. Hungate on the subject of termite nutrition particularly relating to energy and nitrogen metabolism. A metabolic model proposed by Hungate (1939) which predicted that the end products of protozoan digestion were short-chain fatty acids subsequently absorbed and catabolized by the termite, has proved remarkably resilient when subjected to the scrutiny of more recent investigators.

Our knowledge of the taxonomy and biology of organisms inhabiting the termite gut was extended greatly during a period stretching from roughly 1925 to the early 50's by investigations conducted by Harold Kirby, Jr. of the University of California. Pioneering studies on caste determination were also carried out during this period by Castle (1934) and Miller (1942).

An event which was to have a profound influence on future efforts to develop novel control strategies for subterranean termites occurred during 1939, with the establishment in Gulfport, Mississippi, of a USDA laboratory facility dedicated to the study of termite problems. Now part of the USDA Forest Service, this laboratory remains the country's primary federal laboratory assigned the task of evaluating experimental termite-control chemicals and procedures.

Under the direction of Mr. H. R. Johnston, the Gulfport laboratory began an extensive series of investigations on the efficacy of soil treatments to protect structures against subterranean termites. The first long-term soil-treatment tests were installed in Gulfport during 1943. The cyclodiene pesticides, discovered at about this time, were first incorporated into the testing program with the inclusion of chlordane in 1948. Other USDA investigators participating in the Gulfport testing program over the years have included Virgil K. Smith, Raymond H. Beal, Richard V. Smythe, Glenn R. Esenther, Fairie Lyn Carter, Joe K. Mauldin, Michael I. Haverty, Ralph Howard, and Susan C. Jones.

Although field tests of the cyclodiene insecticides had already been underway for three years, the soil treatments recommended in the USDA Farmer's Bulletin No. 1993 (1951), included a 10-percent aqueous solution of sodium arsenite, a mixture of 1 part trichlorobenzene to 3 parts No. 2 fuel or diesel oil, and either a 5 percent solution of DDT or pentachlorophenol in one of these oils. Coal-tar creosote was also suggested but acknowledged as being inferior to the other chemicals. It was cautioned that sodium arsenite, although valuable, was extremely poisonous and should not be used where it might be hazardous to man and animals.

With nearly five years of effectiveness in soil tests in southern Mississippi, chlordane was first marketed in 1952, and the character of termite prevention and control was forever changed. The pest control industry was provided with a family of chemicals that were inexpensive, simple to apply, and gave promise of perpetual protection -- an elixir for the post-War housing boom. By 1960, the truly extraordinary nature of the cyclodienes was appreciated and ground-board test plots were established at seven additional locations across the country to evaluate treatment persistence in varying soil types and rainfall patterns (Carter et al. 1970).

During the 50's several new names appeared on the roster of termite researchers. In California, David H. Kistner began work on what would turn into a life-long study of the taxonomy and systematics of the termitophilous beetles. Dr. Kistner also carries the distinction of having started and continuously edited an American journal devoted exclusively to studies on social insects and their allies,"Sociobiology".

Dr. Frances M. Weesner has had a long and distinguished association with Colorado State University and the National Pest Control Association.

Her early studies with S. F. Light on anatomy, colony foundation and general biology of the termites of the western states have been highly praised. With Dr. Kumar Krishna of the American Museum of Natural History, she coedited a comprehensive two-volume treatise covering virtually all that was learned about termites from 1935 through the mid-60's. The "Biology of Termites" (1969, 1970) endures as a valuable source of information for students and researchers of termite biology.

Dr. Margaret S. Collins is a notable termite authority who began her studies during the 50's in association with A. E. Emerson at the University of Chicago. A collaboration with Glenn Richards apparently influenced much of her early efforts toward studies of the water relations of the termite cuticle. Dr. Collins was associated with Howard University for many years until retirement. She now holds an emeritus position with the U.S. National Museum in Washington, D.C. where she is actively pursuing research on the termites of Middle and North America.

The events and personalities of the 60's were to exert a major effect on the future of termite biology. In 1962, Rachel Carson published a book titled, "Silent Spring", which raised serious questions concerning the fate of modern synthetic pesticides in the environment. This book almost single-handedly ushered in a new era of awareness and public concern over the use and potential misuse of pesticides. For the first time the costs to society of persistent insecticides such as DDT were discussed. Although the validity of her arguments have been argued endlessly, the impact of this book has been felt; in 1972, DDT was removed from the U.S. market by the Environmental Protection Agency.

With the exception of work in progress at Gulfport, and control studies carried out by Dr. Walter Ebeling at the University of California, much of the research conducted on subterranean termites during the 60's was of a basic nature. Following a five-year association with L. R. Cleveland at the MCZ, Dr. William L. Nutting accepted a position at the University of Arizona in Tucson where he conducted unparalleled investigations on flight behavior of desert termites. His direction of basic ecological studies on desert termites in conjunction with the U.S. International Biological Program, Desert Biome from 1970 to 1976 was especially productive.

Dr. Elizabeth McMahan also began her termite studies during the early 60's. Noted for her early work on termite feeding relationships in Hawaii with Dr. Henry A. Bess and later studies on polyethism and behavior, Dr. McMahan currently maintains an active research program on termites at the University of North Carolina, Chapel Hill. Dr. Alastair Stuart is recognized for his contributions to the study of termite communication behavior at Amherst College.

The rudiments of a major breakthrough in our approach to termite control and prevention were visible in a series of experiments begun in the early 60's by scientists at the University of Wisconsin in conjunction with Dr. Glenn R. Esenther of the USDA Forest Products Laboratory at Madison and Raymond Beal at Gulfport. Esenther et al. (1961) reported a termite 'attractant' from fungus-infected wood, a discovery later used in developing the bait-toxicant method of controlling subterranean termites (see review by Esenther and Beal

1978). This method of control is based on the knowledge that a slow-acting nonrepellent insecticide presented to foraging termites in conjunction with an 'attractive' bait substrate has the potential to eliminate or suppress termite activity with minimal pesticide exposure to non-target organisms. The significance of this work might not be apparent until the rate of pesticide delivery is analyzed for traditional soil treatments.

Pimentel and Levitan (1986) have shown that nearly 500 million kg of pesticides are applied to ca. 148 million hectares annually in the U.S. The rate of application of insecticides to agricultural lands averages ca. 2.17 kg h^{-1}; forested lands, less than 1 kg h^{-1}; and household land, 8.33 kg h^{-1}. While the figure for urban land is, by comparison alarming, the figure is based primarily on data describing consumer-applied insecticides and does not account for commercial applicator delivery of termiticides. A simple calculation based upon the fact that an average-sized home with 185 square meters of floor space requires ca. 7.25 kg chlordane (A.I.), suggests that soil termiticides are being applied at the rate of 390 kg h^{-1} in the United States. The total area being treated annually at this rate is impossible to predict accurately. Nonetheless, in Louisiana, where the mean number of annual termite treatments since 1982, has been 35,711 (Arceneaux, personal communication), we can predict with reasonable certainty that ca. 258,900 kg of soil termiticides have been applied to 663.5 hectares. The percentage of the nation's approximately 75 million single-family dwellings treated annually for subterranean termites is not known but considered small by Beal et al. (1983).

Based upon data from the 1970 summary of U.S. Census of Housing, Louisiana had 1,146,000 single-family dwellings. Taking into consideration that 1982-1986 treatment figures provided by the Louisiana Department of Agriculture are based upon considerably more existing structures than were present in 1970, we can estimate that somewhat less than three percent of the state's homes are treated for subterranean termites each year. Insufficient data are available to extend this estimate to the national level but the point is clear; termite treatments deliver an alarming quantity of pesticides into the urban environment.

Ostaff and Gray (1975) calculated that only 0.5 g of the toxicant, mirex were needed to effectively suppress termite activity on urban residential properties. These data suggest that slightly less than 18 kg of insecticide would be necessary to treat homes in Louisiana compared to the 258,900 kg actually delivered.

Although an extensive review of progress with bait toxicants would be interesting, it is beyond the scope of this paper. Early encouraging results were waylaid by the cancellation of the EPA registration for mirex, the toxicant universally adopted for baiting studies. More recent use of amdro[r] by Su et al. (1982) and IGRs at Gulfport (Beal, personal communication) have yet to prove as promising as early work with mirex. Nonetheless, it seems obvious that much attention should be focused on this promising technology.

The hope of discovering novel new chemicals for subterranean control becomes less of a reality each year. As Michael Dover and Brian Croft have recently noted (1986), "The easy chemistry has been used up." Costs of research and development for new pesticides are approaching the $20-45 million range (Dover and Croft 1986) with lead times of 8-10 years.

Despite these odds, a new class of compounds has been synthesized for termite control by Dr. Glenn Prestwich at the State University of New York, Stony Brook (Prestwich et al. 1981), and is being tested in the field at Gulfport to determine potential for use as bait toxicants (Prestwich et al. 1983). A number of additional new compounds, including insect growth regulators, are also being tested by the USDA Forest Service at Gulfport (Anon. 1984, Jones in press)

Nevertheless, most new candidate chemicals for subterranean termite control including the bait-toxicants will likely be drawn from the ranks of already-registered agricultural pesticides as has been the case with recently registered soil treatments. Chlorpyrifos (Dursban[r]), registered for subterranean termite control in 1980; isofenphos (Oftanol[r]), registered but not currently marketed; and permethrin (Dragnet[r] and Torpedo[r]), registered in 1985, are excellent examples of this trend. A logical, albeit untried, approach for developing baiting toxicants, might involve methods to reformulate existing compounds to mask their repellency and fast-acting nature.

The events of the last fifteen years suggest more than ever a need for alternatives to the soil termiticides. In 1972 the Federal Insecticide, Fungicide, and Rodenticide Act of 1947 was revised giving the EPA greater powers to regulate pesticide usage. By 1978, virtually all uses for the cyclodienes had been canceled by the EPA except for subterranean termites control. In 1981, a little recognized report on the contamination of living areas by chlordane was published by J. M. Livingston and C. R. Jones in the Bulletin of Environmental Toxicology. The first indication of a what would become a barrage of media attention to the chlordane issue came on September 13, 1982, when National Public Radio aired a story about chlordane on its popular evening new digest, "All Things Considered." In early March, 1983, retail sales of chlordane in Massachusetts were terminated during a meeting of the Registration Subcommittee of that state's Department of Food and Agriculture Pesticide Board. At about the same time a number of front-page newspaper articles reported homes had been contaminated with chlordane and aldrin on Long Island. Then, on Sunday, April 10, 1983, The CBS weekly news program, "60 Minutes", ran a thirteen-minute story on the chlordane issue and a truly national debate devolved.

In December, 1984, the state of New York announced permanent regulations restricting the use and sales of cyclodiene termiticides. It was also reported that draft regulations were being prepared under which chlordane, heptachlor, aldrin, and dieldrin could possibly be banned (Anon. 1985a). New York became the first state to categorically ban the use of cyclodienes for all uses including termite control when the Department of Environmental Conservation issued an emergency 60-day order in the middle of March (Anon. 1985c). In April, 1985, the Terminix Corp. reported that its European exporter had ceased shipments of Aldrin 4E[r] and that the termiticide would no longer be available in the United States "due to rising costs associated with product support and the competitive nature of the business in a limited market" (Anon 1985b).

Massachusetts' earlier 14-day ban on the sale of chlordane would become permanent on September 9, 1985 (Anon. 1985d). New York officials indicated in

October, 1985, that they would follow Massachusetts' lead making their temporary emergency ban permanent (Anon. 1985e).

The current fate of the cyclodiene termiticides in the United States is uncertain at best. While alternative soil treatments are available, it is the feeling of this author that no effort should be spared to develop alternative termite control methods.

In late-1983, the pest-control trade magazines reported a new termiticide based on the principles of biological control. Spear[r], a formulation of the parasitic nematode, *Neoaplectana carpocapsae* F., entered the marketplace with no published field-efficacy data whatsoever. At the same time, it was reported that research in Dr. Minoru Tamashiro's laboratory conducted by Dr. Jack Fujii had demonstrated that the same parasitic nematode did not control field populations of *Coptotermes formosanus* Shiraki in Hawaii (Weidner 1983). In February, 1985, the results of field tests carried out by Raymond Beal at Gulfport (Mix 1985) suggested little promise of successful termite control with nematodes.

Another recent event has been the introduction of termite-sniffing dogs to the pest control industry (Anon. 1985f). Used to make termite inspections, these dogs are supposedly more capable of identifying termite infestations than humans.

I have already drawn attention, albeit superficially, to the contributions of our nation's pioneering termite scientists and many of their second-generation academic descendants. But what has been happening in the more basic areas of termite research recently? Since October, 1980, I have been compiling a list of workers identified by abstracting services as authors of scientific papers on termites (La Fage unpublished). Although still incomplete and not completely reconciled, more than 1,200 termite scientists have been identified world wide. While this number is large, it is clear that many have made one-time contributions to the termite literature as students, research assistants, and statisticians. Among 245 Americans so noted, only about 25 are generally recognized as having a continuing interest in termite research. These individuals are listed in Table 1.

Table 1. List of active termite researchers in the United States as of February, 1986.

Name	Location	Specialization
Raymond Beal	USDA Forest Service, Gulfport	Control
John Breznak	Michigan State University	Nutrition, biochemistry, microbiology
Michael Chambers	Clemson University (Student)	Control, behavior
Margaret Collins	U.S. National Museum (Ret.)	Behavior, taxonomy
Walter Ebeling	Univ. California, L.A. (Ret.)	Control
Glenn Esenther	USDA Forest Service, Madison (Ret.)	Control
Kenneth Grace	Univ. Calif. Berkeley (Student)	Behavior, pheromones

Table 1. List of active termite researchers in the United States as of February, 1986. (cont.)

Name	Location	Specialization
Michael Haverty	USDA Forest Service, Berkeley	Cuticular hydrocarbons
Susan Jones	USDA Forest Service, Gulfport	Behavior, control
David Kistner	Calif. State Univ., Chico	Termitophiles
Kumar Krishna	Am. Museum of Natural Hist.	Taxonomy, phylogeny
Jeffery La Fage	Louisiana State University	Behavior
Peter Luykx	University of Miami	Cytogenetics
William MacKay	New Mexico State University	Ecology
Joe Mauldin	USDA Forest Service, Gulfport	Physiology, control
Clarence McDaniel	USDA Forest Service, Gulfport	Chemistry
Elizabeth McMahan	University of North Carolina	Behavior
Timothy Myles	University of Arizona (Student)	Behavior
David Nickle	U.S. National Museum	Taxonomy
William Nutting	University of Arizona	Behavior
Glenn Prestwich	State Univ. NY, Stony Brook	Defensive chemistry
Michael Rust	Univ. California, Riverside	General biology
Rudolf Scheffrahn	Univ. Florida, Ft. Lauderdale	Physiology, control
Alastair Stuart	Amherst College	Communication behavior
Nan-Yao Su	Univ. Florida, Ft. Lauderdale	Behavior, control
Minoru Tamashiro	University of Hawaii	Control, pathology
Barbara Thorne	Harvard University	Behavior
James Traniello	Boston University	Pheromones
Deborah Waller	Louisiana State University	Behavior
Frances Weesner	Colorado State University	Behavior, taxonomy
Walter Whitford	New Mexico State University	Ecology
Charles Wright	North Carolina University	Air sampling

During roughly the same period (1981-1985), I have also been monitoring termite research throughout the world using a weekly ASCA[r] literature search. Data for five complete years are summarized in Tables 2-4. A total of 421 literature citations were identified. There was no obvious pattern of number of publications per year except that considerably fewer were recorded in 1981 and 1985 than in the other three years surveyed (Table 2).

Table 2. Summary of termite research (1981-1985) by year.[a]

Year	Number of published papers
1981	64
1982	109
1983	80
1984	102
1985	66
Total	421

[a] Data derived from a summary of author's 4-year ASCAr literature search.

Table 3. Summary of termite research (1981-1985) by region.[a]

Region	Number of published papers
Asia	63
Australia	40
China	19
Europe	111
Japan	6
US and Canada	144
Eastern Europe and USSR	5
Africa	24
Middle East	9
Total	421

[a] Data derived from a summary of author's 4-year ASCA[r] literature search.

More than 34 percent of the total number of publications were written by American authors (Table 3). One hundred and eleven papers were published by Europeans but many were based on work done outside of Europe, primarily in Africa. It should be noted that Australia continues to contribute strongly to the termite literature as does India (included in "Asia").

A summary of subject areas in which termite research is being conducted is shown in Table 4. There was nearly as much work done in the areas of physiology, biochemistry, and behavior as in all others combined. The distribution of efforts in the United States generally follows the world pattern.

Table 4. Summary of termite research (1981-1985) by subject.[a]

Subject	Number of published papers	
	World	US
Behavior (including trail pheromones)	77	21
Biological control	10	3
Chemical control	34	20
Ecology and demographics	45	19
Economic impact, crop loss	15	1
Genetics	4	3
General biology	18	2
Physiology, biochemistry, microbiology, etc.	119	50
Effects on soils	24	2
Taxonomy, systematics, evolution, phylogeny	44	7
Relationships with fungi (mutualistic)	11	4
Termitophiles	8	8
Testing procedures	12	4
Totals	421	144

[a] Data derived from a summary of author's 4-year ASCA[r] literature search.

One might pose the question, "Is funding for subterranean termite research concomitant with economic impact?" The cost of termites to the U.S. public, defined in terms of dollars spent for prevention, treatment, and repair of single-family dwellings has been estimated between $100 million and $3.5 billion annually (Beal et al. 1983). Mauldin (1982) argued that the actual figure is close to $750 million. Recent estimates published by the Southeastern Branch of the Entomological Society of America, Insect Detection, Evaluation and Prediction Committee (Hamer et al. 1985) suggest that subterranean termites cost nine southeastern states more than $472 million during 1983. Using a commodity by commodity comparison we see that Termite costs were greater than those for pests of soybeans ($150.12 million), cotton ($169.75 million), beef, dairy, and poultry ($265.63 million), forestry ($15.25 million), rice ($25.47 million) and sugarcane ($4.88 million). In spite of these figures, to my knowledge, not even a single grant has yet been awarded to study termite biology and control under the USDA Competitive Grants Program.

One might argue that Hamer's (1985) figures are grossly inaccurate; they probably are. Nevertheless, data for Louisiana suggest that control costs alone (not including value of repairs) have averaged nearly $18 million annually during the past three years (La Fage and Arceneaux unpublished).

Looking to the future, we can say with some certainty that the disproportionately low level of funding for termite research available during recent years will be insufficient to meet tomorrow's demands. It can also be argued that without better data-collection procedures to assess economic impact, we will be unable to provide the 'proof' necessary to convince the USDA and Congress that additional funding is necessary. I have already described a state-mandated report form being used in Louisiana since December, 1985, which provides accurate information on termite treatment patterns (La Fage in press). Other states should consider following Louisiana's lead in this area.

I wish to briefly identify one additional personal concern beyond those already mentioned. I find the pest-control industry generally poorly informed about termite biology. With concerns over pesticides, insurance, and other aspects of business, pest-control operators appear to have suffered a gradual decline in their level of biological competence. If control methods like the bait-toxicant system are to be successfully implemented, PCOs will have to commit to a greater understanding of the animals they seek to control. A better training paradigm is needed.

The question of which avenues of research should be followed in the future is indeed a difficult one to answer. There are the obvious needs for alternative control procedures. But, what about basic research? Here we find a clear and urgent need for taxonomic studies. Feeding, foraging, and general ecology studies are warranted as their results can be used immediately in developing bait-toxicant strategies. But what of investigations on termite DNA? And what of questions about the evolution of eusociality itself in these enigmatic insects? There is much to be done, and considering the current state of soil treatments, perhaps little time in which to do it. The challenge is ours.

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INSECT GROWTH REGULATORS

Gerardus B. Staal
Zoecon Corporation
975 California Avenue
Palo Alto, Ca 94304,
USA

Although the first IGR's with juvenile hormone activity were registered more than ten years ago and the subject therefore could be assumed to have reached a stage of middle age maturity, some of their better potentials have only started to be exploited quite recently. The reason for this is primarily in the fact that these IGR's present a new mode of action that is orders of magnitude slower than that of conventional pesticides. It has been difficult, even for researchers finding near complete control of confined insect populations in the laboratory, to become convinced that something this slow could significantly affect insects under field conditions and yield economical and more satisfactory control than anything used before. I am talking here specifically about the advances made in the control of cockroaches and fleas in the home environment. However, the subject of IGR's is broader than that. Not only are newer types of IGR's with juvenile hormone activity (more succinctly called "juvenoids") likely to be added to the the old and proven ones such as hydroprene and methoprene, but other insects of economic importance may be found to be equally worthwhile targets for this group of compounds. In addition to this, the term IGR's formally also includes chemicals with a different mode of action such as agents with anti juvenile hormone activity (AJHA), chitin inhibitors such as diflubenzuron and various others with less explored potential or less clearly understood mode of action. Most of the research and development has been done on the juvenoids, however, and these will be the main subject of my presentation.

Juvenoids

Historically, the synthesis of juvenoids with insect control potential was preceded by the chemical identification of the naturally occurring insect juvenile hormones, which , at least as a group of closely related homologs, turned out to be rather ubiquitous for insects in general. These juvenile hormones were found to be essential regulators of insect development, particularly with respect to metamorphosis and reproduction. Externally induced excess (juvenoid application) or deficiency (AJHA application) proved to be capable of derailing the development process thoroughly and irreversibly, leading ultimately to population collapse.

The slowness of the mode of action of juvenoids has been their most important handicap. In the earliest practical applications, those for fly and mosquito control, this was of little concern since neither flies nor mosquito's respond with a delay in metamorphosis and the larval stage is rarely of economic importance anyway. The criterium here is whether the adult stage can be prevented from developing, which is exactly what juvenoids do well.

In another group of application targets, the fate of individual early generations of multivoltine species was of less concern than the build up of harmful later generations. Thus, even some multivoltine lepidopterous field pests fell into the realm of practical application, although it should be very clear that continuing larval damage in mono- or bivoltine species in most field crop situations is usually not acceptable and therefore does not fall into this class. Ultimate population control for these situations would be an important achievement but is usually compromised by the migratory potential of the adults of these species.

More confined conditions counteract the immigration of untreated adults and it is no coincidence that the present uses of juvenoids concentrate on more or less confined environments such as bodies of water (mosquito larvae), cattle manure (flu spp.), mushroom houses (mushroom flies), silos and other facilities in which stored products are kept, greenhouses, and, last but not least, the home environment.

The step from using conventional insecticides to the use of our modern juvenoids which act through inhibition of reproduction is a large one for the uneducated user. He will probably expect instantaneous miracles from his spraycans on well established populations of cockroaches, although he must also be aware of the temporary nature of the success of any prior attempts to deal with the problem with the means available in the past. Fortunately, the introduction of better pest management in the home can be stimulated not only on the educational level, but also by marketing combinations of conventional insecticides and juvenoids, thus combining the best of both worlds (this approach has some potential of counteraction of the ingredients and may therefore not work out for all chemical classes of juvenoids and insecticides). It is very likely that maintaining low cockroach populations once they are initially brought down with combinations of conventional insecticides and juvenoids will require applications of juvenoids only, but this needs further experience with this novel tool.

Generally, all juvenoids prevent normal adult metamorphosis and result in either intermediates between larvae and pupae, pupae and adults or between nymphs and adults. Such intermediates are invariably unable to reach the adult stage because they cannot molt succesfully again even if their internal molting hormone secretions try to induce them to, which is unfailingly immediately lethal. However, in the majority of cases in cockroaches, these intermediates do not attempt to molt at all, continue to feed and may persist for a very long time, often exceeding the lifespan of normal (reproductive) adults. Morphological intermediates induced by hydroprene in *Blattella germanica* are invariably and irreversibly sterile and this is the main asset in the population control strategy. It has turned out to be an important practical feature that the morphological deformations resulting from juvenoid treatment in any individual are predictors of total sterility (at least for hydroprene in *B. germanica*). It should be emphasized that treatment of otherwise unaffected adults does not produce significant sterility by itself, only deformed adults or "adultoids" which were exposed to the juvenoid during a critical period early in the last nymphal instar will show the permanent sterility complementing the external abnormalities.

The mechanism through which juvenoids can induce this total sterility has not been fully investigated, but since this sterility is invariably irreversible and can only be induced in the same critical period as other morphological effects, it is thought to be a related phenomenon, affecting the metamorphosis of the internal reproductive organs. A closer look at the female gonads of sterile *B. germanica* reveals various abnormalities ranging from entirely atrophied to hypertrophied oocytes. Corresponding sterility of the males has also been documented. The finding of internal abnormalities makes it less likely that behavioral abnormalities such as courtship failures play a dominant role in the juvenoid induced sterility.

The critical period for the induction of sterility may seem to limit the usefulness of IGR's of this type because cockroach populations are usually not very synchronous and contain individuals of many different ages and stages. However, experiments by our research group and many collaborators have established that this does not constitute a problem for a compound such as hydroprene because of an unusual set of properties that may be unique for this compound.

We found that hydroprene combined volatility with a high degree of affinity for certain finished as well as unfinished surfaces, on which it remains available to the cockroaches. This means that residues of hydroprene, perhaps largely independent of the method of application, will relocate to favorable surfaces including those in places that are rather inaccessible to conventional treatment. Cockroaches may thus not be able to escape exposure by hiding out as they are known to do for conventional insecticides, most of which are repellant to cockroaches. We have no evidence indicating that hydroprene residues have any degree of repellancy for insects. It is hard to determine what these assets will accomplish in treatments that combine volatile juvenoids with conventional insecticides, but one may surmise that the usual cockroach strategy of avoidance or hiding out until residues have disappeared will be of no use in avoiding hydroprene. The effectiveness of combined treatments was confirmed in test in apartments in San Jose (Ca), in which combination aerosols (propetamphos and hydroprene, applied at 0 and 3 months) reduced the population in 8 month to about 2 % of the starting size. The final small number included a majority of deformed cockroaches, indicating that a further decline could be expected (Fig.1).

Another important and unexpected property we found was that hydroprene residues accumulate in the debris (frass, exuviae, etc.) of cockroach populations in surface treated cages. These debris residues then can affect subsequent generations of cockroaches under conditions in which the same residues applied to cage surfaces without a resident cockroach population would long have ceased to be active. This leads to the unique conclusion that hydroprene may be more, or at least not less, effective in dense populations than in scarce populations. We do not know of conventional insecticides with this unusual combination of properties.

All in all, the control of cockroaches has reached a new frontier in which a degree of control can be reached that has not been seen before. It is expected that after the population decline has taken effect, the degree of close to full control can easily be sustained by maintenance sprays of hydroprene alone at infrequent intervals, primarily to take care of fresh immigrants. The mobility of hydroprene residues could well have its drawbacks in situations in which outside air is conditioned rather than recycled, leading to a disappearance of volatile material. We surmise, however, that cockroaches do not prevail under those conditions and will probably retreat into habitats without drafts and with higher humidity. So far, no data appears to be available on cockroach control with juvenoids in tropical areas, where cockroaches may take refuge in the outdoors. However, the use of hydroprene alone indoors may well be effective under these conditions.

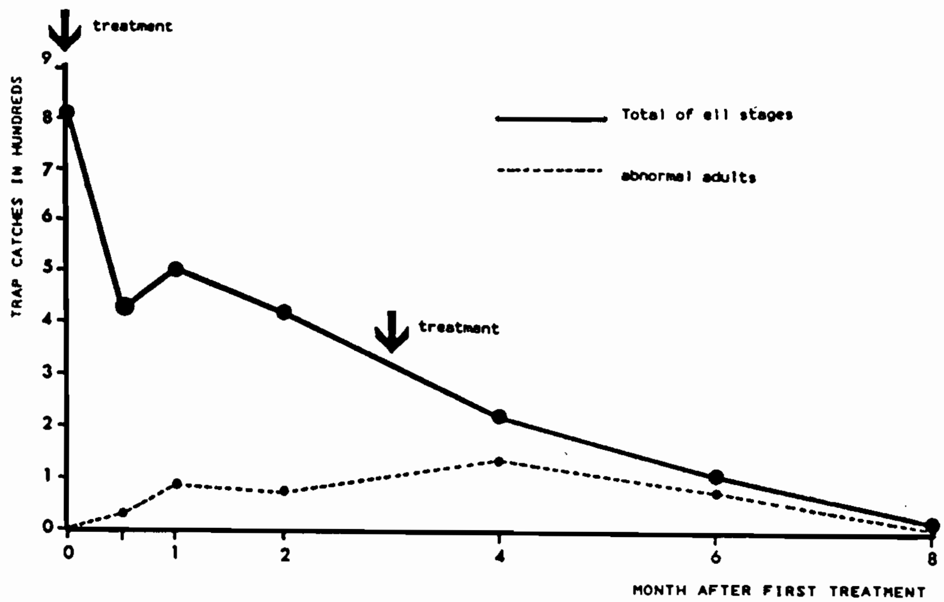

Fig. 1. Decline in *Blattella germanica* population in a block of 34 apartments after treatment with foggers containing hydroprene and propetamphos (one 12 oz. can containing 0.6 % hydroprene and 1 % propetamphos per 700 sq ft apartment).The population of cockroaches was monitored at indicated intervals with 3 sticky traps per apartment during 24 hrs. The graphs depict the total catch in all apartments. In addition to the apartments, the semi open crawlspace under the block was similarly treated since it harbored a sizable population of *B. germanica*.

Other properties that make juvenoids desirable household insecticides are the virtual absence of toxicity for organisms other than insects and the absence of repulsive odors for humans. The combination of residue mobility, persistence in the dwelling, volatility, and the absence of repellancy probably accounts for the high degree of control observed in residences treated with hydroprene. Yet, it usually takes 4 to 5 months to obtain significant population reductions if hydroprene is used alone and almost double that for larger species such as *Periplaneta americana*. In a typical situation, the first deformed *B. germanica* can be observed after 7 to 10 days, which, because of the association with sterility, provides unique feedback to the user about the efficacy of the treatment at an early stage.

Methoprene is a companion product of hydroprene and was originally registered as a mosquito larvicide. It is presently in use for a variety of different insect targets, primarily in confined environments. It shares with hydroprene many characteristics and physical properties but it is probably slightly less volatile and is orders of magnitude less active on *Blattella* *germanica* and other cockroach species. However, it is the compound of choice for the control of indoor breeding flea populations (on which hydroprene is less active) through similar mechanisms as already described. The difference here is that the larvae are not usually noticed and therefore do not constitute a nuisance. The juvenoid takes effect primarily at the moment of adult emergence. The cycle is thus stopped, in this case without permanently deformed individuals.

The usual application method of methoprene in homes is through foggers, aerosols and sprays aimed at carpets, upholstery and pet bedding materials. The efficacy of this type of application for reaching the breeding sites of the flea larvae in the pile of carpets etc appears to be high, while the persistence in these materials is significant. Recent reports have it that methoprene vapors can affect flea eggs in early developmental stages. This would not only serve to help explain the phenomenal success of the treatment, but possibly also open up a way to control the flea population by treating the animal host with methoprene. In the case of fleas, the reintroduction of unaffected reproductive adult fleas from the outside is a major concern; it will depend on the circumstances whether a recommendation for additional adulticide control through insecticide collars etc. needs to be made. The desirability of flea control around the perimeter of homes as a third line of defense will depend on the magnitude of the flea breeding potential at these sites which is not clearly established and probably dependent on the climate, if it is at all significant.

For termites, juvenoids have not established their economic efficacy, although laboratory research has shown significant effects. The foremost effect here also is the derangement of metamorphosis by JH effects, but this mode of action is usually overshadowed by a short term defaunation effect, meaning the suppression of symbiotic migroorganisms that are essential in the predigestion of their principal food - cellulose fibers. At this time the exact mechanism is unknown and not reconcilable with other methoprene effects described. The net result is starvation and severe population reduction. Another, longer term, effect is the derailment of caste determination, leading to a preponderance of soldier development. This ultimately results in an unfavorable energy balance affecting the survival of the colony. Effects on reproduction of the queen have also been noted. Taking all these effects into consideration, there is little doubt that juvenoids have great potential as termite control agents, provided that the economics of the application through impregnation of structural lumber and the persistence in this substrate are favorable. Alternatively, juvenoids may be suitable as a component of baits. The incentive for the extensive amount of research still needed in this area may be provided by the curtailment of the use of standard chlorinated hydrocarbons.

The use of juvenoids for ant control is well established. Their slow mode of action and absence of repellancy at active dose rates fit within the requirements for effective ant control which requires trophallactic transfer from returning foragers to brood and queen(s). Thus, effective control can be obtained with methoprene on pharaoh ants. Other juvenoids such as Pro-drone and fenoxycarb have proven their value for the control of imported fireant.

The development of juvenoid baits for other ant species will probably be affected more by the difficulties experienced in optimizing compositions of dependably attractive bait formulations than on the proven intrinsic effectiveness of candidate juvenoids.

Anti juvenile hormone agents (AJHA)

Although the principle of JH antagonism bears the promise of even faster action than juvenoids because premature metamorphosis can stop larval damage, extensive research has not yet resulted in compounds with practical utility. However, many novel chemical substances have shown the practicality of the idea in laboratory tests and hope persists that better compounds may be found. It has become increasingly economically impossible to develop novel compounds specifically for urban insect control, making it mandatory that other major insect tests are identified as primary targets. The compounds with AJH activity found to date have narrower selectivities for target insect taxa than the juvenoids (e.g. either for Lepidoptera only or for Heteroptera and Acrididae combined in the case of the precocenes) and the most common urban insect pest species have not been part of this spectrum as yet. Since the process of discovery of novel insecticides has become more rational and less random, concentration of primary assays with novel compounds on major pest targets is a direct cause of this. Given the fact that the endogenous juvenile hormones of all insect species are very closely related in the chemical sense, there seems to be no essential reason why more broadspectrum compounds of this type could not be found.

Apart from premature metamorphosis and associated inability to survive, let alone reproduce, AJHA will also have the capacity to inhibit reproduction through exposure of otherwise unaffected adults, a feature that is generally not found in the juvenoids.

Chitin inhibitors

The selectivity of this group of compounds is primarily restricted to larvae of Lepidoptera and Diptera with little or no activity on other insect groups and adults in general, although a few other effects such as on the reproduction of cotton boll weevil have proven to be of practical value as well. At this time, no significant activity has been found on the most important target insects in the urban environment with the exception of the pronounced effect of these compounds on the larvae of various species of flies and mosquitoes. The impressive environmental stability of compounds of this class does not seem to offer significant advantages in the indoors urban environment.

INSECT PHEROMONES

William J. Bell
Department of Entomology, University of Kansas, Lawrence KS

Pheromones are chemical signals, synthesized and released by insects and other kinds of organisms, for communication in mate-finding, courtship, foraging, spacing and aggregation behavior. These chemical signals are analogous to calls, vibrations and visual signs also used by insects in communicating.

During the past 20 years the sophistication of our techniques for collecting and characterizing pheromones has steadily progressed. We now have an impressive catalog of known insect pheromones, many of which have been synthesized. However, Klassen et al. (1982), reviewing the status of research and development on pheromones and attractants found that of 610 species for which pheromones are known, 31% have been used in detection measures, 2% in mass-trapping, 1% in monitoring and 0.5% in disruption.

Southwood (1981) suggested that "... pesticide misuse is the use of the wrong pesticide or the use of too much of the right one, so that it is distributed in the wrong place or at the wrong time." In this context, Wall (1984) recommended that "communication chemicals can be used for ... improving the efficiency of conventional pesticides and ... suppressing pest populations without pesticides." The objective of my report is to describe the major strategies for employing communication chemicals in pest insect management, to provide examples of typical programs, and to suggest a few new avenues of investigation. As a conceptual framework, I suggest that we transfer technology to urban entomology from agricultural and forest entomology, where pheromone research has been quite active and has led to practical benefits.

Detection

Pheromone traps, impregnated with sex or aggregation pheromone, can be an effective means for detecting the appearance of a given species in an area where the species has not been found previously or where it has been eradicated. The information obtained can be used to implement a management plan appropriate for the particular species discovered. For example, pheromone traps have been successfully used to detect Mediterranean fruit flies, *Ceratitis capitata* (e.g., Burk and Calkins 1982) and gypsy moths, *Lymantria dispar* (e.g., Schwalbe 1980). In some instances, detection of a particular pest species leads to conventional insecticide usage or to some sort of biological control program, whereas in other instances pheromones play a significant role in the management plan (e.g., mass-trapping).

The potential for detection systems in crops, stored-grain and forests has now reached a significant level owing to the number of available pheromones and the degree of sophistication among pest management workers. For example, aggregation pheromones of stored-grain beetles are currently used to detect infestations, suggesting the need for insecticidal treatment (literature in Burkholder 1981). Urban entomology has lagged behind other major entomological areas in exploiting pest species through their own communication channels. Perhaps the urban environment, because it is constructed so differently physically and sociologically from other environments, is simply inappropriate for these kinds of tools. However, the scientific literature and the trade journals suggest that there simply has been less attention paid to using pheromones in urban systems than in other systems.

Two things need to be done to remedy the situation. First, since a large number of species that are urban pests are also pests of agriculture or forestry, information and techniques can be transferred for use in urban systems. Gypsy moth traps examplify how this has already been done for a species that invades urban as well as woodland areas. Secondly, a comprehensive plan needs to be developed for urban systems. A starting point would be to (1) formulate a list of the most pervasive of the insect pest species, (2) cross-check the list against lists of known insect pheromones, (3) assess ways to employ pheromones against species for which the chemicals are known (including behavioral analyses), and (4) determine how best to direct efforts for future pheromone identification.

Monitoring

Pheromone traps can be used to monitor the level of a pest population over time, perhaps before, during and after a program is implemented to manage the pest. Pheromone traps in agriculture are used primarily to monitor phenological timing of adult activity so that control efforts can be applied at the most effective point in time.

Substantial preliminary information is required before one can make any sense from monitoring data: (1) relationship between trap catch per unit time and the real population size, (2) range of attractany of the pheromone used in a trap, (3) duration of trap effectiveness, (4) quantity of material that should be used in the trap, (5) extent to which natural pheromone emitters compete with traps for the target individuals. In addition, practical matters may enter into the scheme, including determination of the most optimal trap placement sites and other procedures.

An important prerequisite for interpreting data obtained through monitoring is the establishment of an acceptable level for a given pest species. Wood et al. (1981) and Zungoli and Robinson (1984) examined the responses of people to cockroach infestations and found a good correlation between actual population size and assessment of the infestation by people. There also does seem to be a threshold (aesthetic injury level) that can be identified, below which people are less concerned and above which they are most concerned about a pest insect infestation.

Mass-trapping

The objective in mass-trapping is to reduce a pest population after monitoring indicates that the population has reached some economic, health or sociological threshold. Reducing the population may simply affect mating success, if a sex pheromone is employed, or may be aimed at the reduction of individuals causing damage.

Research has recently been undertaken on pheromones for the control of the European elm bark beetle, *Scolytus multistriatus*, the carrier of Dutch elm disease (Lanier 1978). Sheets of white cardboard covered with adhesive were used with a pheromone dispenser fixed to one corner. Each bait, in a slow-release formulation, contained the equivalent of 5 million virgin females and was released at the rate of 2000 females per hr for about 100 days. The attractant used was a mixture of three aggregating pheromones: an alcohol, 4-methyl-3-heptanol, a bicylic ketal, α-multistriatin, and a sequiterpene, α-cubebene (Pearce et al. 1975). The absolute amounts of pheromone released are very small; for example in one 800 ha area, 115 g was released over a 160 day period.

Considerable effort was spent determining the most optimum trap design, placement on utility poles, and color and hue of the trap surface. It appears that beetles attracted by the pheromone tend to land on the most conspicuous object, such as the white traps against a dark background. Traps must be installed in late spring before the emergence of the beetles, because during the early spring healthy elms are most susceptible to infections by the Dutch elm disease fungus spores rubbing off the bodies of beetles feeding in twig crotches. Another important strategic factor is that the bark beetles undergo a dispersal flight of up to 600 m before they respond to pheromone (Lanier 1978). Trap placement only near infested trees therefore would not be effective in curtailing spread of the beetle. At Fort Collins, CO 1.5 million beetles were trapped, resulting in a decline of Dutch elm disease rate from 3.5% in 1974 to 2.8% in 1975. While the measure has not had complete success in every test area, at North Syracuse NY and at the University of Delaware, the DED rates dropped from 7.1% to 4.4%, respectively, to zero.

Most of the data from mass-trapping of cockroaches, using food attractants or similar lures, indicate that population levels are not significantly reduced by this method. In fact, Reierson and Rust (1977) reported that daily trapping of German cockroaches, *Blattella germanica*, in the laboratory reduced the population only when the number of cockroaches exceeded the available harborage; small populations were unaffected. These kinds of data may simply indicate that we need more information about the population dynamics and movement patterns of cockroaches in urban environments and that better attractants, such as pheromones, should be found. Research into the first problem is currently underway in several laboratories (e.g. M. H. Ross, F. E. Wood), and our knowledge of cockroach ecology is growing (Schal et al. 1984). The acquisition of better attractants, especially pheromones, seems to be muddled by industrial secrecy and a paucity of research.

Attractants of various sorts have been reported for several other important urban pests, but in most cases the usefulness of these attractants has thus far not been established. For example, male sex pheromones occur in the mosquitos, *Culex pipiens, C. tarsalis* and *C. quinquefasciatus* (Gjullin et al. 1967). In addition, volatile compounds associated with egg rafts are attractive to female mosquitos (Osgood 1971), and gravid females *Aedes aegypti* are attracted to water containing immature larvae (Soman and Reuben 1970). The female sex pheromone of the housefly, *Musca domestica* and the face fly *M. autumnalis*, attract males to fly-like visual objects (Carlson et al. 1971); whether or not the pheromone has useful field application is somewhat controversial. Since negative data are seldom published, it is difficult to know if researchers have not followed up on leads such as these or if the research has been completed and the tests unsuccessful.

Disruption/confusion

The disruption tactic involves interfering with normal chemical communication by confusing target species with large quantities of synthetic pheromone or by adapting or blocking olfactory receptors. One case in agriculture where mating-disruption using pheromones has been repeatedly successful, is that of the pink bollworm, *Pectinophora gossypiela* (Doane and Brooks 1981; McVeigh et al. 1983). Approximately 15 gm/ha applied over the entire pest season, may cause most females to remain infertile and thus bring about a substantial reduction in the larval pest population in the next generation (McLaughlin et al. 1972). More recently, Flint and Merkle (1983) showed that permeation with only one component of the two component pheromone blend in gossyplure inactivated males and caused disruption due to the imbalance in pheromone composition ratios. There are other cases of disruption attempts in progress, although none in urban systems, and with more research, some of these cases may yield results.

Use of pheromones in conjunction with biological control or conventional insecticides

A major problem in combating urban pest insects is the occurrence of physiological and behavioral resistance. If selection for physiological resistance to an insecticide follows the rules for natural selection, then we would expect to generate resistance more quickly if the insects are nearly continually exposed to it. Thus any method that reduces exposure, while still applying a measure of control, is less likely to lead to resistance than a method that involves more continual exposure.

Behavioral resistance is now recognized as an important factor in pest management, especially in urban systems, and more specifically with cockroaches and flies. For example, avoidance of insecticides by cockroaches can be as serious as physiological resistance to insecticides: to obtain a lethal dose of a surface insecticide, cockroaches must walk on it; if they avoid the insecticide, they will not receive a lethal dose.

The tactic of combining, periplanone B, the sex pheromone of the American cockroach, *Periplaneta americana*, with a conventional insecticide (propoxur) (Bell et al. 1984), is one example of drawing cockroaches to a lethal dose of insecticide rather than counting on the cockroaches randomly encountering the insecticide for their lethal dose. The result, if the formulation is used properly, is that cockroaches need not be continually exposed to the insecticide. In addition, since male and females more commonly walk on propoxur mixed with periplanone B than on propoxur alone, the addition of the sex pheromone to the insecticide seems to reduce behavioral resistance. Another example is the use of aggregation pheromone extracts to overcome repellancy of insecticides in the German cockroach (Rust and Reierson 1977a,b). Whereas it may be quite difficult and may require a substantial amount of time and investment to prepare volatile pheromones applicable for all cockroach species, it may be somewhat easier to find natural products of cockroaches that would reduce behavioral resistance when these compounds are added to insecticides.

The use of ant pheromones, in combination with poison baits, seems to be a relatively unexplored area. In species of the ant, *Myrmica*, trail-following behavior can be elicited by a single poison gland compound, 3-ethyl-2,5-dimethylpyrazine (Evershed et al. 1982). In the pavement ant, *Tetramorium caespitum*, the pheromone is a mixture of 2 pyrazines (Attygalle and Morgan 1983). The trail pheromone of the pharoahs ant, *Monomorium pharaonis*, faranal, is a sesquiterpene aldehyde (Ritter et al. 1977). Dufour's gland secretions of ants often enhance trail-following behavior, as with the mixture of alkenes and alkanes, primarily (Z)-8-heptadecene, from Dufour's gland in *Myrmica* (Morgan et al. 1979). Both Dufour's gland and poison gland secretions are deposited by foraging workers moving between the nest and a food source, and the mandibular gland secretion, acetaldehyde, acts as a short-distance attractant (Cammaerts and Cammaerts 1980). It would seem that given this much information about the chemicals involved and the behaviors elicited by the chemicals, that the communication of some ant species could be exploited to efficiently direct workers into transporting poisons to the nest. Similar information is available on at least 5 other common ant species.

Food baits or parapheromones (pheromone-like compounds) mixed with insecticide have been used successfully to manage yellow-jacket foragers. Wagner and Reierson (1969) suppressed *V. pensylvanica* in southern CA using cat food-mirex mixtures and a chemical wasp attractant, and Ennik (1973) was able to reduce the numbers of foraging yellow-jackets by 75 to 95% with two days of exposure to cat food mixed with several insecticides. Davis et al. (1967) reported that 2,4-hexadienyl butyrate was a highly specific, potent lure for *V. pensylvanica*. Cartontraps baited with heptyl butyrate was an effective measure in a peach orchard in Oregon; yellow-jackets had stopped peach harvesting, but after introduction of the traps, harvesting could be resumed (Davis et al. 1973).

An interesting development is the exploitation of kairomonal responses to entomophagous insects by attracting higher than normal populations of parasites and predators. In nature, individual insects expose themselves to predation or parasitization every time they emit a signal, and so by amplifying this signal, predators and parasites are able to work more efficiently in locating their prey or hosts. For example, certain species of the parasitic wasp, *Trichogramma*, locate *Heliothis zea* populations by homing in on the hosts sex pheromone; Lewis et al. (1982) have shown that parasitization of host eggs can be increased using synthetic host pheromone. Shapas et al. (1977) reported that *Trogoderma glabrum* could be attracted by its female sex pheromone to a source .of pathogenic protozoa *Mattesia trogodermae*.

In conclusion, it seems as though the applicability of using pheromones in urban pest management has really not been rigorously investigated. The necessary research has hardly begun. If we can draw any conclusion at all, perhaps it is that the use of pheromones in urban systems may very well work best in combination with biological control agents, growth inhibitors or conventional insecticides. When there is a requirement to draw insects to a central point for purposes of inoculating them or giving them a lethal dose or directing parasites toward them, pheromones have enormous potential.

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BIOLOGY AND HABITS OF THE OLD HOUSE BORER, *Hylotrupes bajulus* (L.)

William H Robinson
Department of Entomology
Virginia Polytechnic Institute
and State University
Blacksburg, VA

The old house borer, *Hylotrupes bajulus* (L.), is an important insect pest of structural wood in eastern and southeastern United States. The larval stage of this cerambycid feeds on seasoned softwood timber, preferring the sapwood portions of pine, fir, and spruce. Larvae will not live in rotten wood, and the oils, resins, and lignin content of the heartwood portion of wood make it an undesirable food. Larvae can feed for several years in softwood timber, and large populations can cause cosmetic and structural damage.

H. bajulus is native to the Atlas Mountains of North Africa (Hartnack 1939), and now occurs on all major continents (Becker 1979). It was first recorded from North America in 1875 (Robinson and Cannon 1979), and is now known to occur from Maine south to Florida, and west to Michigan and Texas (USDA 1971). There are records of this insect occurring in California (Garnett 1918), but pest populations have not been reported from western states.

Although *H. bajulus* has been reported living in a wide variety of climatic conditions, it is most common in temperate regions, and especially along the coasts of continents. Old house borer biology and distribution in England were reviewed by Parkin (1934) and Hickin (1975); in France by Serment (1976); in Denmark by Wichmand (1931) and Rasmussen (1961); in Germany by Becker (1942) and Cymorek (1974); in South Africa by Tooke and Scott (1944) and Durr (1954, 1957); and in the United States by Moore (1979) and Cannon and Robinson (1981, 1982, 1983). In South Africa, *H. bajulus* is reported living in dead trees, branches, stumps, and other forest debris, and is only secondarily a household pest (Weidner 1936, Durr 1954). In Europe and England this beetle is less often encountered in a forest environment, and more often as a structural wood pest (Durr 1954). In the U.S. the old house borer has not been reported living in forest debris, but only as a pest of structural wood. Cannon and Robinson (1982) reported finding *H. bajulus* larvae and adults at a lumber mill containing seasoned and unseasoned wood.

The life history and habits of the South African, northern European, and North American populations of *H. bajulus* vary considerably and are considered biotypes (Durr 1956, Cannon and Robinson 1983). These individual biotypes have evolved after introduction into areas and subsequently became isolated by geographic or climatic barriers (Becker 1979).

The objectives of this paper are to review the biology and habits of the North American and European biotype of *H. bajulus*, including information on pest status, economic impact, strategies for control, and offer prospectives on future research.

Biology and Habits

The old house borer spends 2 to 10 years of its life in the larval stage. The development rate of larvae is affected by ambient air temperatures (85-88 degrees F optimum), relative humidity (80-90% optimum), wood moisture content (10+% optimum), and nutrient content of the wood (high ash and protein content). In favorable conditions, larvae can complete development in about two years. However, the development time is usually 3 to 6 years, and severe alteration of environmental conditions can extend the time to 10 or more years. Contrary to its common name, the old house borer in the U.S. occurs primarily in structures less than 10 years old (Cannon and Robinson 1982).

The survival and development of H. bajulus larvae are strongly influenced by relative humidity and the resulting wood moisture content of infested wood. Schuch (1937) reported larval growth to take place fastest at satursted atmospheric humidity resulting in 27-28% moisture content in pine wood. The wood moisture content of interior household woodwork fluctuates during the spring, summer, fall, and winter seasons (Bois 1959). The life cycle of this longhorned beetle is closely correlated with the seasonal fluctuation of wood moisture content. Adult beetles emerge and lay eggs when the wood moisture content is increasing; larvae penetrate and begin their long feeding period when wood moisture content is at the year°s peak.

June, July, and August. Adult old house borers usually begin emerging from infested wood in early June and continue into July (northeastern and mid-Atlantic states). There are records of adults emerging in May and August in Pennsylvania (Robinson and Cannon 1979), and a greater range of emergence may occur in southern latitudes. The moisture content of household timber in eastern and southern U.S. ranges from 10% to 17% during June, July, and August (Bois 1959).

Adult beetles mate soon after emerging. Males vigorously pursue females, sometimes tearing off legs and antennae before and after mating occurs. White (1954) reported that females need mate only once to lay their full complement of eggs, and Cannon and Robinson (1981) reported that fecundity and egg viability were not significantly different between single and multiple (6.8 matings) mated females. Cannon and Robinson (1981) observed that H. bajulus males can mate at least six times without a reduction in their ability of transfer a viable spermatophore or for recipient females to lay their entire complement of eggs. Females of the North American biotype lay an average of 165 eggs (Cannon and Robinson 1983).

Males appear to recognize and locate females at short distances through antennal contact. Apparently chemical attractants play only a minor part in bringing together potential mating pairs. Doppelreiter (1979) reported a female sex pheromone for H. bajulus. Males appear to be attracted to regions of infested wood containing teneral, unemerged females (unpublished data). Adults are most active in the daytime when temperatures are between 29-35 C (85-95 F), and fly when temperatures are above 30 C (86 F) (Cymorek 1968). Under ideal conditions adult females live about 10 days, and males about 15 days.

Soon after mating the female deposits several (2-6) batches of eggs in cracks, crevices, or between two surfaces of wood. The oviposition period lasts about five days, and a mean of 4.3 egg batches are laid per female. The ovipositor contains numerous chemo- and mechanoreceptors that guide the female in selecting an oviposition site (Mares and Robinson 1986).

The female H. bajulus has an elongated ovipositor comprised of the modified abdominal segments 8 and 9, intersegmental membrane 8/9, and a pair of distal gonostyli. The ovipositor can be extended to a length of 35 mm, and when not in use, it is retracted within abdominal segment 7. Females prefer to lay eggs in cracks 0.016 to 0.25 mm wide, and on rough surfaces to a depth of about 20 mm (Mares et al. 1986)

Under optimum conditions (80+ F and 70% relative humidity) old house borer eggs hatch in about nine days (Cannon and Robinson 1983). Upon hatching the first-instar larvae bore into the wood substrate a short distance and begin feeding. The tunnels made by the early stage larvae are usually parallel to the wood grain and close to the surface. As the larvae feed, the tunnels become packed with frass. The feeding of early stage larvae is usually not audible.

September, October, and November. In the fall larvae continue to feed in the wood, and grow larger. The sound made by the mandibles of medium- or large-sized (100+ mg) larvae scraping the wood can be heard from a distance of several feet. Pallaske (1983) reported a short-term periodicity of 20 minutes for larval feeding. In general, old house borer larvae have an active feeding phase of 23 to 32 days alternated with inactivity phases of eight to 14 days (Pallaske 1983). By the end of the fall season (November), the wood moisture of structural timber declines, and this is soon followed by a decline in feeding by old house borer larvae. During this period the moisture content of household structural wood ranges from 7% to 15% (Bois 1959).

December, January, and February. There is a decline in the feeding activity during the winter months, when the moisture content of the wood substrate is 10% or lower. H. bajulus larvae are in close contact with the wood and are apparently affected by the level of moisture in the wood.

March, April, and May. Larvae resume more regular feeding when the wood moisture content rises above the low levels achieved during winter. In the spring the wood moisture content ranges from 6% to 13% (Bois 1959). Transformation into an adult occurs when larvae have reached the weight of approximately 200 mg. Individual larvae tunnel to the surface of the wood and cut an oval exit hole. The larva retreats into an enlarged pupal chamber, and packs the access to the exit hole with long, fiberous pieces of wood. The pupal period requires approximately 20 days, and culminates with the formation of the adult beetle. The adult remains in the pupal chamber for several days before removing the frass plug and emerging to the outside.

Larvae that have not reached the weight of approximately 200 mg continue to feed in the wood. Cannon and Robinson (1981) reported on old house borer larvae growth under the combined effects of tmeperature, relative humidity, and wood moisture. Wood consumption and growth were severely limited in the fluctuating environmental conditions of a house attic (24.5+ 10.8 C, 7.6% wood moisture, 75.5+ 9.5% relative humidity). Cannon and Robinson (1986) reported that larval feeding and growth were significantly reduced at temperature extremes of 15 C and 35 C. The optimum temperature for old house borer larvae growth is between 20 C and 30 C. This correlates to the average daily range in temperature in the wall of a frame house in June (Duff, 1980). Cannon and Robinson (1981) reported house attic temperatures of 24.5 to 35.3 C during July to October.

Pallaske (1983) reported that the larvae rotate on their longitudinal axis while feeding, apparently to prevent the excessive abrasion of one mandible. The frass produced by the larvae is slightly granular, and composed of small (1.1-1.2 mm long), barrel-shaped pellets of digested wood and irregular shaped particles which have not passed through the digestive tract. Larvae generally feed parallel to the grain of the wood. However, large chambers may be produced in sections of wood favorable for larval development. Becker (1943) reported that H. bajulus larvae can digest cellulose.

As old house borer larvae feed in wood, they produce pheromones that are excreted with the frass (Higgs and Evans 1977). When there is a small number of larvae and a small amount of frass produced, the concentration of pheromones can stimulate old house borer females to oviposit in the wood. When there are several larvae feeding in the wood and a large amount of frass produced, the concentration of pheromones can be repellent to ovipositing females (Higgs and Evans 1977).

Control

Control of H. bajulus infestations includes the use of both chemical and non-chemical methods; and the method of choice varies with the degree of infestation and the geographic location.

Heat sterilization of wood to kill larvae has been used in central and northern Europe, and Russia (Jensen-Storch and Hendricksen 1932, Reickhardt et al. 1930). Temperatures maintained above 88 C for several hours will kill old house borer larvae (Durr 1954). Vongkaluang (1978) reported on the effectiveness of extremely low temperatures, achieved by the application of dry ice to the surface of infested wood, in controlling H. bajulus larvae.

Removal of infested wood has been used as a control means in Europe and the U.S. Jensen-Storch (1933) reported that by removing 71% of the infested wood 69% of the larvae were eliminated.

Biological control agents for controlling the larval stage include beetles (Cleridae) and parasitic wasps (Braconidae, Ichneumonidae). The larvae of clerids Opilo mollis L., O.domesticus L., and Corynetes coeruleus Deg. are predators of old house borer larvae. The effectiveness of these predators has been reported by Steiner (1938), Wichmand (1941), and Becker (1943). The braconids reported as parasites of H. bajulus larvae include, Doryctes leucogaster Nees, Rhoptocentrus piceus Marshall (Eckstein 1934), and Atanycolus longifemoralis Marsch. Kuhne and Becker (1974) reported Scleroderma domesticum Klug. as a parasite and predator of H. bajulus. In general, biological control of the old house borer has not been investigated in the U.S., and little is known of the potential parasites. Adults of the braconid, R. piceus, were recovered from a modern log house in Virginia (Robinson, unpublished data).

Whole-house fumigation for old house borer control with hydrocyanic acid, methyl bromide, or sulfuryl fluoride has been used in northern European countries (Jensen-Storch 1932), and the U.S. This method has proven effective in killing larvae in infested timbers.

Treatment of wood with organophosphate and carbamate insecticides, creosote, pentachlorophenol, lindane and a variety of copper, zinc, and metallic napthenates is effective in preventing initial infestations or reinfestations of old house borer larvae. Durr (1954) reported extensively on the toxicity of wood preservatives and insecticides to _H. bajulus_, including the penetration of chemicals into various kinds of wood. Robinson et al. (1981) reported on the effectiveness of insecticides and wood preservatives in killing eggs, first-instar larvae, and adults of the old house borer. The British Standards Institution (1977) has established laboratory methods for determining the toxicity of wood preservatives against _H. bajulus_.

Economic Importance

Large or prolonged infestations of _H. bajulus_ larvae may cause structural damage to wood, i.e., weaken the load carrying capacity. The cost to prevent or control active infestations, and to replace damaged or infested timber provides a large part of the pest status and economic importance of this insect. Serment (1976) reviewed the world distribution and importance of _H. bajulus_.

There is little information on the economic importance of the old house borer in the U.S. As a pest of structural wood, St. George et al. (1957) reported this insect second only to subterranean termites. Nolan and Brady (1985) estimated damages and control costs from old house borers in the state of Georgia to be over $1.5 million. Williams and Smythe (1979) reported on the estimated losses caused by wood-infesting beetles for several southern U.S. states, but did not delineate beetle species.

Current Research

Research on the biology and control of _H. bajulus_ is being conducted in Europe and the U.S. The laboratory of Sigfried Cymorek and Reiner Pospischil of Desowag-Beyer in Krefeld, West Germany contains a large colony of the old house borer. For many years this colony has provided material for S. Cymorek's research on the biology and control of _H. bajulus_. Current research projects in this laboratory include the oviposition behavior of adult females, and chemical control of larvae (R. Pospischil, personal communication)

Pallaske (1983, 1984) recently completed research on the mechanism, behavior, and feeding periodicity of _H. bajulus_ larvae. The results of this work show that the feeding behavior of the larvae is marked by periods of activity and inactivity. This information can be applied to designing methods of detecting and evaluating active infestations of this insect. Decisions based on hearing the feeding sound made by the larvae may be in error if the inspection is conducted during an extended period of larvae inactivity.

Research in the U.S. has been conducted at North Carolina State University. and at the Urban Entomology Laboratory at Virginia Polytechnic

Institute and State University (conducted by K. F. Cannon, J. M. Mares, and B. L. Dodson). The old house borer colony used in the research was established from adults and larvae collected in Virginia and surrounding states, and represents the North American biotype (Cannon and Robinson 1983). The research has included the morphology of the female ovipositor, the biology of adults and larvae, and the chemical control of adults and larvae. Recent research includes the penetration into wood by organophosphate insecticides using water or an organic solvent as the carrier. Further work includes the determination of the toxicity of insecticide concentrations that penetrate structural wood.

Future Research Needs

The research base for the biology and control of the old house borer in the U.S. is small, and has been restricted to studies in the mid-Atlantic states. However, the need for information on this insect is increasing. Within the last ten years, H. bajulus has increased its distribution and economic importance in the southern states, especially Florida (Robinson, unpublished data). This wood-infesting insect will continue to increase its economic importance in eastern U.S., and perhaps expand its distribution to include west coast areas.

Future research on the old house borer should consider the following projects:

[] The distribution of H. bajulus in the U.S. The most current information shows a discontinuous distribution in eastern U.S., and isolated records in central and southern states. More accurate data would benefit prevention and control strategies used by professional pest control operators, builders, lumber mill operators, and homeowners.

[] The economic importance of H. bajulus in the U.S. There is little or no data on the cost of replacing damaged wood, or prevention, or control of this wood-infesting insect. Joint research projects with wood technology groups and demonstrating the economic losses due to this insect pest may help to increase awareness and financial support for research.

[] The potential for biological control. There is little data on the biology and habits of the hymenopteran parasites and predators of H. bajulus in the U.S. The potential for nematode, and bacterial pathogens should be investigated.

[] The pheromones produced by H. bajulus larvae and adults, and the attractant chemicals in preferred oviposition substrates (pine, spruce, fir). Although Higgs and Evans (1977) reported on a pheromone for the old house borer larvae, Doppelreiter (1979) reported a female sex pheromone, and alpha- and beta-pinenes have been identified as attractants to ovipositing females (Becker 1943), little research has followed.

[] The chemical protection of wood, and the chemical control of old house borer larvae within wood. Since Durr (1954) reported on the penetration of pesticides in wood to kill old house borer larvae, few research projects have followed. The potential of protecting structural wood with low concentrations of insecticides should be more thoroughly investigated.

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THE BIOLOGY AND BEHAVIOR OF THE GERMAN COCKROACH: AN OVERVIEW

Donald A. Reierson
Department of Entomology
University of California, Riverside

The importance and impact of the German cockroach, Blattella germanica (L.), on the urban entomology scene cannot be overstated. It is a tremendously significant pest, accounting for a high proportion of the research in industrial and structural entomology and being of major concern nearly everywhere indoor pest control strategies are used. Besides being a common nuisance, cockroaches have been implicated as being directly or indirectly involved in allergies, outbreaks of illness, and transmission of a variety of pathogenic organisms (Schulaner 1970; Fernandez and Zaror 1971; Alcamo and Frishman 1980). Their association with cluttered, damp and unsanitary conditions and their tendency to live near where food is stored and prepared makes them suspect as carriers of disease.

The purpose of this presentation is not so much to provide specific information from our laboratory but rather to promote interest and discussion about the biology and control of this important urban pest. We hope that the discussions which will follow will provide an opportunity to share research findings, point out shared areas of concern, and motivate research in new and creative directions.

German cockroaches are excellent test insects because large numbers of them can be cultured relatively simply and quickly, they are durable and fairly easy to handle, and they generally respond to stimuli in a consistent and predictable way. Because of their economic importance, most research with German cockroaches ultimately involves their control. However, many concepts established through work on this insect have been found to be valid and important for fields of study such as ecology, genetics, physiology, and insect behavior. For instance, research by Walter Ebeling on the effect of desiccant aerogels on cockroaches promoted or revitalized studies concerning the physiology of cuticular wax formation, insect desiccation, harborage selection behavior, and repellency and learning in insects. Similarly, research with cockroaches at VPI & SU has for many years affected our views of insect genetics, insecticide resistance, reproductive physiology, and population dynamics.

A literature review we are in the process of completing indicates that more than 2,500 reference articles concerning the German cockroach have been published. It is ironic that in spite of the amount of published information about it, this insect continues to be so poorly understood and difficult to control. There is apparently no consensus concerning basic questions such as its diet, feeding habits, mating behavior, selection of shelter, aggressiveness, or response to environmental conditions and insecticides. The list of presumably important topics in this regard can easily be expanded to include many others. Perhaps the difficulty in getting a consensus involves the insect itself and the wide variety of conditions and settings under which it is found and has been studied. Cockroaches generally respond in a specific way to specific stimuli but it is often difficult or impossible to eliminate extraneous or competing stimuli or to have a similar set of conditions every time cockroaches are studied. It is our task as researchers to make relevant, reproducible generalizations based on interpretation and analyses of observations made through good scientific method. Cockroaches respond differently according to variations of physical factors such as light, temperature, and humidity, and to biological factors such as thirst, hunger, stage of growth, and population density. The summation of these and many other factors results in complex and sometimes unpredictable responses by cockroaches.

German cockroaches are prolific insects, a single mating under optimal conditions resulting in up to 45 to 50 young from each of 6 to 8 oothecae, there being a hatch of a capsule about every 25 to 40 days. Significantly fewer young are produced by cockroaches resistant to certain insecticides but even they produce about 30 to 35 young per egg capsule. This rapid high level of fecundity contributes to sustained problems in instances where only a portion of the population has been controlled. The sequential development of the cockroach through a series of seven stadia (i.e., instars) depends on titers of specific hormones and may be affected by competing chemicals or by upsetting the delicate concentration balance necessary for successful maturation.

There are numerous questions being asked about how populations of cockroaches become established, how they are maintained, and how they enlarge or spread. A great deal of research in the last several years has involved the distribution and movements of the German cockroach. No substance has been shown to effectively and consistently attract this species, aggregation pheromone presumably being more of an arrestant than attractant and active primarily after being contacted by the insect. Apparently certain stages of a population of German cockroaches close to adequate shelter, water and food are the first to disperse as crowding increases (Ross et al. 1984) and tend to follow intersections and direct passageways to other nearby suitable areas where they may become established. Runstrom and Bennett (1984) found this to be the case in apartments with common plumbing versus ones where there was no interconnection. In work with baits, we observed that movement patterns of cockroaches from an established population may vary greatly but that most movement occurs in the dark and tends to be fairly restricted and directed, most cockroaches staying close to a preferred harborage site. Insecticidal fogs or sprays, increasing numbers of cockroaches in limited shelter areas, or decreased amounts of readily available food or water also significantly increase movement. Foraging and movement from shelter have a pulse pattern and may be related to conditions in the harborage. Emergence from harborage is sequential, nymphs coming out first, but only a small percentage emerge in any 24-hour period. Our videotapes indicate that male cockroaches come out next but that most of the insects that do come out stay close to food if it is nearby. We have observed very little mating outside of shelter even though some courting does take place by food sites. Most cockroaches emerging from shelter to which they have become accustomed return to it after foraging.

In preliminary laboratory experiments we found a minimum threshold number of German cockroches was usually needed for the successful development of a population in a new site. Although we have not quantified the effect, single females or very small groups of nymphs often die when introduced into a sterile environment having no shelter, even if food and water are present. Their difficulty may be related to psychochemical stress, common in many other insects. Once established, the rate of growth of the population depends on environmental factors and eventual size may be limited by the area of suitable undisturbed dark harborage, provided adequate food and water are available. Competition for space in the shelter, aggression, and inter-cockroach interference with ritualized sexual behavior and courtship may inhibit growth under crowded conditions. We have even observed cannabalism of young as they emerge from oothecae and of others as they moult.

Trapping, flushing and visual assessment are the usual methods of cockroach population monitoring and surveillance. Each method has advantages and disadvantages. We use jar traps because it is convenient and reportedly fairly accurately reflects the composition of the population being sampled (Owens and Bennett 1983). Flushing is theoretically most disruptive but trapping relies on cockroach movement and can be influenced by placement, the configuration of the trap, or a variety of other factors. Various kinds of sticky traps effectively sample cockroaches but they are generally biased towards catching adults. Nymphs apparently do not get caught in the adhesive as easily as adults. Ballard and Gold (1983) reported that more cockroaches could be captured in electrified can traps, but consistent catch may be more important than absolute catch if we assume that even efficient trapping has limited effect on the size or composition of the population being sampled. More work is needed to help interpret surveillance observations. It is likely that the age-class distribution of what is seen or trapped could help provide useful information about a population including its location and stage of development. Marking trapped individuals and recapturing them has also provided useful information, especially concerning patterns of movement, migrations and dispersal, and the theoretical size of the population. One of the limitations of marking has been that nymphs do not retain their external label through their moults. Perhaps internal marking with dyes or other unique chemical substances will eventually assist making recapture data even more useful.

Physiological and psychological factors probably also affect the establishment and subsequent development of populations of German cockroaches. They prefer warm places (about 26°C) and avoid excessive dryness but can go without free water and food for several days (Gunn 1935; Willis and Lewis 1957). They have a propensity for enclosed dark places and usually travel close to edges and intersections, often walking the same pathway repeatedly. Their tendency to live in warm, mesic environments is probably attributable to their relatively high cuticular permeability (19.9 $g/cm^2/hr/mmHg$) and temperature sensitivity (Appel et al. 1982). They learn their surroundings quickly and will explore new objects placed close by. Although a great deal of information has been generated concerning the physiology of this insect, much more work is needed in the area of behavioral and ecological physiology. Perhaps future research will indicate habitat modifications or other novel approaches we can use that will help control this pest or prevent it from occurring as a problem.

Two areas of cockroach biology receiving a great deal of attention lately are learning and repellency. These subjects are especially important because they influence our perceptions about the behavior of cockroaches and how cockroaches react in the environment. Because they are so closely allied, we have tended to group learning and repellency together in discussions about cockroach reactions to chemicals. Actually, repellency involves avoidance behaviors that may be reinforced and eventually lead to learned behavior. Both are of practical importance because even very active materials like silica aerogels or some pyrethroids may be ineffectual if cockroaches avoid them or do not remain in contact with them long enough to be killed or accumulate a lethal dose (Ebeling et al. 1966, 1967; Rust and Reierson 1977). Silica gel, for example, may kill cockroaches confined to it in less than 2 hours but is almost useless as an insecticide if untreated areas are made available to the cockroach so that it has an opportunity to avoid it. The same is true to a greater or lesser extent for most of the insecticides we have experimented with. In comparing three methods, including choice boxes, slant boards and harborage cartons, Schneider and Bennett (1985) concluded that cockroaches might be repelled by certain insecticides but that laboratory tests using any of these materials were of limited value in predicting the influence of repellency under field conditions. However, cockroaches will avoid many natural and synthetic chemicals, including insecticides. Inazuka (1982) reported strong repellency of compounds isolated from oils of Japanese mint, Mentha arvensis, and Scotch spearmint, M. spicata, the most active compounds being pulegone and carvone. Similarly, Koehler and Patterson at the University of Florida (pers. comm.) have tested a variety of proprietary non-insecticidal compounds which are nearly totally repellent to German cockroaches. It is not surprising, therefore, that cockroaches avoid some insecticides. Our research has shown a high correlation between choice box results and ultimate performance under field conditions, failures not necessarily being due just to repellency. The benefit to the insect of avoiding toxic substances may be overcome by high activity (as in the case of cypermethrin used by Schneider and Bennett 1985) where even a brief initial contact may result in kill. The insect may also be overcome by formulation, such as microencapsulation, or with a bait, where lethal amounts of insecticide adhere to the cockroach or continue to act upon it even as the insect tries to escape or moves to an untreated place.

Learning is represented by retained behavior modified through experience. Cockroaches readily learn and retain information about their surroundings and that ability may be affected by an assortment of factors including the type of experience (i.e., punishment) involved, crowding, or chemicals. Sublethal toxicity may be viewed as a type of punishment. The exact definition and context of cockroach learning varies among researchers and more work is needed to quantify or verify its relevance in pest management strategies.

Another major subject of concern and disscussion has involvled the documentation and relevancy of genetically controlled metabolic insecticide resistance in the German cockroach. Resistance in field-collected populations is not new (Bennett and Spink 1968; Collins 1977), but there are differences of opinion as to how important it may be in controlling this pest.

Although Dr. Cochran from VPI & SU has also documented resistance in field-collected cockroaches, he reports at this conference and elsewhere that control of cockroaches in his area is not a problem and that resistance may have little effect on control. We have demonstrated topical resistance of up to about 14-fold with organophosphate insecticides and >250-fold to carbamates. Some level of resistance has been found with each of 16 toxicants we have tested, including amidinohydrazone, pyrethroids, and avermectin. Significant resistance was found in about two-thirds of the random samples of cockroaches we collected from 100 restaurants in Los Angeles, CA. Although others claim that resistance is not problematical, we believe control is often inadequate because of resistance and that good control is attainable in those instances only with excessive care and thoroughness of application. Perhaps intensive sampling would show poorer control than they believe they are presently enjoying. Cockroaches are the only household insect pests for which scheduled retreatment with insecticide is necessary and which will quickly develop to large numbers after treatments are stopped. Most registered insecticides are very active against cockroaches. For example, using susceptible cockroaches, only 0.38 μg/insect (7.6 mg/Kg) topically applied chlorpyrifos will kill them. But even 127 $mg/in.^2$ (19.7 mg/cm^2) residues are not sufficient to kill all of some resistant strains we have collected. Because of the dose involved, direct sprays and thorough heavy residues are effective but reasonable residues are not. It is likely that there is a dynamic relationship between the absorption of insecticides on surfaces, avoidance of the chemical by the insect, and site desensitization or metabolic detoxification of insecticide taken into the insect that affects the performance of an insecticide. It continues to be a challenge to us to sort out these relationships and to put them into a perspective in order to deal with them constructively.

Besides evaluating new chemicals for controlling German cockroaches, we should be aware of possibilities and limitations concerning use of biological gents, the so-called biorational approach. Rust and Reierson (1977) showed that the performance of insecticides could be enhanced by utilizing aggregation pheromone in combination with them. The insect growth regulators (juvenoids, anti-juvenile hormones, and chitinase inhibitors) also appear to be a promising group of relatively safe chemicals not usually grouped with the conventional nerve-effect toxicants. More needs to be known about them, but growth regulators may help provide a new kind of control by interfering with naturally occurring chemical processes within the insect.

At UC Riverside we are encouraged by the possibilities of using special fungi or other biological agents to help control these insects. Because German cockroaches carry their oothecae nearly to the time of eclosion, parasites have little opportunity to attack the developing embryos. Oothecae of species of cockroaches such as Supella longipalpa, Blatta orientalis, and Periplaneta sp. are much more vulnerable to attack by parasitic wasps and other organisms. There are few, if any, efficient predators or parasites of the German cockroach, but certain fungi may have applicability because of their internal mycosis in cockroaches, resulting in the progressive decline and eventual destruction of a population. We are presently investigating the biology, morphology, and activity of a host-specific Metarrhiza, the first report of an effective internal mycotic agent in the German cockroach resulting in reduced movement, lack of reproduction, and chronic lethal effects by occlusion of circulation and septicemia. More work is needed in this regard but it may be an especially rewarding area because of the fact that new culture techniques and genetically engineered bacteria and yeast are presently available.

I hope this overview has stimulated interest in the biology and control of the German cockroach so that the following discussions will be productive. Of course, there are many subjects and many details about this fascinating and formidable pest that could not be addressed in this brief account. Hopefully, creative and candid discussion and sharing results of our continuing research will help us answer meaningful questions about this pest and better understand its biology and behavior in order to safely and effectively control it.

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INSECTICIDE RESISTANCE

Donald G. Cochran
Dept. of Entomology, Virginia Polytechnic
Institute and State University, Blacksburg, VA 24061

The topic of insecticide resistance as it relates to insect pests in the urban environment is not easy to address. There is a large assortment of species which could be considered under the umbrella terminology used to describe this conference, i.e. urban entomology. Indeed, it might even be difficult at the present time to compile a satisfactory list of insect species for inclusion under this umbrella. Furthermore, even when one considers the most important structural and household pests there is great unevenness in the information available on resistance among the various species. For example, an extensive literature exists concerning resistance in houseflies (Plapp and Hoyer, 1967; Plapp et al., 1976; Chang and Plapp, 1983a; 1983b) and mosquitoes (Ariaratnam and Georghiou, 1975; Malcolm, 1983). In these species, detailed studies have been conducted on the genetics and biochemistry of resistance (Scott et al., 1984; Kao et al., 1984). From this knowledge it is often possible to state how the resistance mechanism is inherited, whether it consists of one or more than one component, and what each component does to impart resistance. Information of this type provides a good understanding of resistance, but does not necessarily point to a way of negating it.

Most pest control operators would not likely consider flies and mosquitoes as their prime target insects. Rather, they usually mention termites, cockroaches and fleas as the pests they are asked to control most frequently. Resistance in termites does not appear to be a problem and probably does not occur. The reason this is the case relates to termite biology. Each colony of termites is largely the result of the reproductive efforts of the queen. It matters little how many colony members are killed by an insecticide treatment because they do not normally contribute to the next generation. Even if the queen is killed she represents only a single individual in terms of selection for resistance. Her loss has essentially no impact on the much larger number of queens (colonies) remaining in the wild. In other words, the potential for selection for resistance in termites is strictly limited.

Insecticide resistance in fleas has been known to occur since the early 1950's (Brown and Pal, 1971). It involved both cat and dog fleas and certain other species as well. Unfortunately, detailed studies of resistance in fleas have been scarce in the recent literature and we do not have a good picture of its current status. Clearly, this is an area which needs greater attention.

Cockroaches, on the other hand, are an important urban pest on which there is a reasonable amount of information dealing with resistance. Since that information has not been covered at this conference, I will attempt to do so in the following pages.

The first point to be made in dealing with cockroach resistance is that it is apparently a problem only in the German cockroach. Several other species were mentioned in the earlier literature as having low-level resistance to chlorinated hydrocarbon insecticides (Webb, 1961). Since then little evidence on resistance has appeared for these larger species like the American cockroach. This fact probably relates to less severe treatment pressure being exerted against these species and their longer life cycle, which, of course, translates into fewer generations per year. This is also an area which needs more study to establish the facts.

In the German cockroach, resistance is a serious problem and there are indications that it is becoming more acute with the passage of time. Historically, high-level resistance to chlordane developed in the 1950's (Heal et al., 1958; Grayson, 1954). As a result, it's use had to be abandoned because resistance became so widespread. This led rather directly to the substitution of organophosphate (O.P.) and carbamate insecticides in cockroach control. Several of these materials are still in use for that purpose.

For ease in understanding resistance, I prefer to consider it in terms of the currently used chemical groups of insecticides and possible mechanisms of resistance. This approach is particularly useful in considering cases of cross resistance. Most of the data to be presented will be given as resistance ratios (RR) which are simply the ratio

$$\frac{LT_{50} \text{ resistant strain}}{LT_{50} \text{ susceptible strain}} = \text{times resistance.}$$

The VPI susceptible strain served as the reference susceptible strain.

Of the available O.P. insecticides, diazinon was among the first to have been widely used in cockroach control. Most field-collected strains now exhibit low to moderate-level resistance to it as shown in Table I.

Table I. Response of Field-Collected Strains to Diazinon.[a]

Strain	Resistance Ratio[b]
Columbia	1.9
Hurt Park	2.7
Bowl	2.7
Tide	2.4
Gates Hudson	2.4
Seasons	1.6

[a] The concentration of diazinon used was 0.03 ul/cm^2.
[b] Based on the LT_{50} method.

This resistance confers cross resistance to chlorpyrifos, malathion, acephate and probably other O.P.'s as well. This suggests a common resistance mechanism possibly involving a phosphatase-type enzyme. Of the materials tested acephate has the lowest RR's, usually less than 1.5. In addition, many field strains have a specific high-level resistance to malathion over and above the diazinon-type resistance. This resistance renders malathion useless against these strains, but it does not confer cross resistance to any other O.P. insecticide. The mechanism of resistance appears to be an enhanced carboxyesterase enzyme in resistant individuals. It is controlled by a simple autosomal dominant gene (Cochran, 1973a).

The carbamate insecticides propoxur and bendiocarb have been used extensively in cockroach control. Unfortunately, resistance to diazinon also confers cross resistance to both of these carbamates. The data for propoxur are presented in Table 2.

Table 2. Response of Field-Collected Strains to Propoxur.[a]

Strain	Resistance Ratio
Columbia	4.4
Hurt Park	6.0
Bowl	4.5
Tide	4.0
Gates Hudson	4.0
Seasons	3.8
Chris	4.4

[a] The concentration of propoxur used was 5.0 ug/cm^2.

It can be seen that the RR's are somewhat higher than for resistance to diazinon and this fact is sufficient to cause concern as to the effectiveness of propoxur in cockroach control. This resistance can be largely overcome by the use of synergists such as piperonyl butoxide (P.B.O.). For example, a RR of 6.0 (Hurt Park) becomes 1.1 in the presence of a 1:5 insecticide:synergist ratio. This result indicates that the resistance mechanism is probably an enhanced oxidase-enzyme capability in resistant strains.

More recently high-level resistance to bendiocarb has been discovered in various field-collected strains (Table 3).

Table 3. Response of Field-Collected Strains to Bendiocarb.[a]

Strain	Resistance Ratio
Columbia	> 40
Hurt Park	> 40
Bowl	> 40
Tide	> 40
Gates Hudson	> 40
Seasons	> 40
Chris	>140

[a] The concentration of bendiocarb used was 10 ug/cm^2.

This is an interesting phenomenon because there are indications that it developed rapidly, perhaps after only one or two exposures (Nelson and Wood, 1982). However, it is not an example of a species-wide natural resistance because several known susceptible strains are completely susceptible to bendiocarb. Bendiocarb resistance can be largely overcome by use of synergists (Table 4). This again indicates an oxidative-enzyme type of resistance mechanism.

Table 4. Effects of Synergists on Bendiocarb Resistance.[a]

Strain	RR	RR(+P.B.O.)	RR(+MGK 264)
VPI Normal	--	1.3	1.2
Seasons	> 40	2.7	2.3
Chris	>140	4.2	2.6
Forest Green	>140	6.2	2.9

[a] The concentration of bendiocarb was the same as in Table 3 and the insecticide:synergist ratio was 1:5.

Pyrethroid insecticides are just beginning to be used in cockroach control. It is quite likely this use will increase in the near future. Therefore, it is important to remember that resistance to natural pyrethrins was reported earlier (Keller et al., 1956; Cochran, 1973b). A recent survey of field-collected strains has revealed that about one third of them have high-level resistance to pyrethrins (Cochran, unpublished data). This resistance can also be largely negated with synergists (Table 5), indicating an oxidative enzyme resistance mechanism.

Table 5. Effects of Synergists on Pyrethrins Resistance.[a]

Strain	RR	RR(+P.B.O.)	RR(+MGK 264)
VPI Normal	--	1.0	1.0
Lynn Haven	> 80	1.2	1.4
Seasons	> 80	1.2	1.2
Kenly	>240	1.6	2.1

[a] The concentration of pyrethrins used was 0.3 nl/cm^2 and the insecticide:synergist ratio was 1:5.

These pyrethrins-resistant strains show only low-level resistance to allethrin and no resistance to several other synthetic pyrethroids. However, one field-collected strain has been discovered which has high-level resistance to pyrethrins, allethrin and phenothrin, moderate- to high-level resistance to permethrin and low-level resistance to fenvalerate. This strain has been exposed to resmethrin and phenothrin as primary control agents for two to three years. Unfortunately, this strain is probably an indicator of what may occur if a shift is made to a control regime which includes only synthetic pyrethroids. It is clear that resistance can develop rapidly under these conditions. Data are not yet available on the possible effect of synergists on this resistance. In addition, there is an indication in the literature that two types of action may exist among synthetic pyrethroids against cockroaches (Scott and Matsumura, 1983). If true, this could possibly extend the useful life of this group of insecticides even if resistance becomes common.

Table 6 is a summary table indicating the status of resistance to eleven insecticides in two strains of German cockroaches. The Chris strain is from San Diego, CA and the Kenly strain is from Kenly, NC. It is apparent from the table that the most serious resistance occurs to malathion, bendiocarb and

Table 6. Typical Resistance Profiles in German Cockroaches

Insecticide	Chris Strain	Kenly Strain
Diazinon	2.1[a]	2.2[a]
Chlorpyrifos	2.4	1.8
Acephate	1.2	1.1
Malathion	> 60	> 50
Propoxur	2.2	6.1
Bendiocarb	>140	> 70
Pyrethrins	1.4	>240
Allethrin	1.6	1.5
Permethrin	1.1	1.0
Phenothrin	1.0	1.3
Fenvalerate	1.0	0.9

[a] Values are resistance ratios (RR).

pyrethrins. In some strains tested, the level of resistance to propoxur and diazinon is somewhat higher than with either of these two strains. However, most strains tested have significant resistance to only one or two insecticides. A few strains are resistant to as many as four materials. Fortunately, control of all of these strains is still possible by carefully choosing the insecticide to be used. That choice should be based on a knowledge of the resistance profile, the relatedness of the chemicals being considered, their mode of action, and their mechanism of resistance.

In addition to the commonly used insecticides, as described above, several other types of materials are available for cockroach control. They include insect growth regulators (IGRs), boric acid and the inert void-treatment dusts. There does not appear to be any resistance to these materials in cockroaches as yet. This is probably true mainly because they have not been used extensively in control. There is no theoretical reason to expect that resistance to these materials will not develop given adequate exposure levels and time.

The cases of insecticide resistance in the German cockroach, discussed above, appear to be physiological in nature as indicated mainly by the action of synergists. The existence of behavioral resistance in this species is perhaps also to be expected, but is not well documented. It may be more extensive than is generally recognized. However, it is important to differentiate between behavioral resistance and the well-known repellency of insecticides (Ebeling et al., 1967; Rust and Reierson, 1978). The latter appears to be more a matter of avoidance behavior or a turning away from treated areas. This response does not necessarily involve a population-selection mechanism by which the behavior in question is enhanced. To have behavioral resistance, I believe it must be demonstrated that a selectiondriven change in a particular behavioral response has occurred in a population. That change could be as simple as an increased frequency of the response within a population, or it could involve an intensification of the response, or it could be a complex of changes. This area appears to be ripe for investigation.

In conclusion, resistance is highly variable among urban pests. It is non-existent in termites, is a potent factor in houseflies, and is of intermediate importance in fleas and cockroaches. This situation appears to be related to the importance of the pest, which probably influences the intensity of the control efforts against that pest. It is also related to the biology of the pest.

While resistance is a serious problem, it appears that most urban insect pests can still be controlled by the choice of an appropriate insecticide. There is an abundance of materials from which to choose. In cockroaches, even the traditional O.P. insecticides still seem to control most strains. Thus, the prospects for continued control of urban pests are excellent.

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BEHAVIOR AND BIOLOGY OF YELLOWJACKETS

Richard E. Keyel
S. C. Johnson and Son, Inc.
1525 Howe Street
Racine, WI 53403

The history of interest in social wasps extends back to ancient times (summarized in Spradbery, 1973; Edwards, 1980). This interest stems from the ability of these wasps to form organized "societies", and from the disproportionate pain, sometimes ending in death, caused by wasp stings. Both the interest and the pain remain with us today, as reflected in the number of recent reviews of wasp biology (Spradbery, 1973; Akre and Davis, 1978; Edwards, 1980; Akre et al., 1981; Akre, 1982; Brian, 1983) and the research effort on yellowjacket control (reviewed in MacDonald et al., 1976).

Because of the wealth of reviews available, I will concentrate on studies conducted in the last few years. In that time, much additional research on yellowjacket behavior and biology has been performed. During the last few years there has also been an explosion of literature on allergies to yellowjacket venom. These immunological aspects of yellowjacket biology could fill a separate review and often are not directly relevent to yellowjacket behavior or biology. Therefore, I will not discuss the allergy aspect of yellowjacket biology.

One of the main emphases of yellowjacket research has always been control. Wasp control research has focused on yellowjackets (see Greene and Caron, 1980 for the etymology of the term "yellowjacket") because they cause the majority of urban problems associated with wasps (Fluno, 1961; Barr, 1974). From 1960 to 1975, much of the yellowjacket research in the United States was aimed at developing control techniques. Foraging wasps from unknown nests have always posed the greatest challenge for control, but with the discovery that 2,4-hexadienyl butyrate and related compounds were attractive to yellowjackets (Davis et al., 1967), it appeared that a mass trapping or enhanced toxic bait system could be developed to control foragers. Unfortunately, many yellowjacket species do not respond to this class of attractants (Grothaus et al., 1973) and several non-repellent insecticides, such as chlordane and mirex, soon became unavailable for use. Thus, the early hopes for a generally effective toxic bait abatement system never were fulfilled. In their 1976 review, MacDonald et al. described the control situation as "bleak".

In 1986, the control situation is little changed, although new toxicants have shown potential and some initial work has begun on more generally effective attractants. Parrish and Roberts (1983, 1984) evaluated methoprene and avermectin Bl for yellowjacket control. Both materials have possibilities as toxicants for *Vespula maculifrons*. However, methoprene in certain bait bases was repellent to foragers and the repellency of avermectin Bl was not tested. Gambino (1984) and also Guzman (1984) reported on the use of nematodes for control of *V. pensylvanica* and *V. germanica*, but these techniques are still in the preliminary stages.

In addition to a non-repellent, slow-acting toxicant, a toxic bait requires an effective bait base. Reid and MacDonald (1986) found texture to be important in the acceptability of meat-based baits. Large amounts of gristle and other materials which are difficult to cut rendered an otherwise attractive bait unacceptable.

An attractant may be useful in yellowjacket control either as a means of mass-trapping (Davis et al., 1973) or to enhance removal of toxic bait (Wagner and Reierson, 1969). Ross et al. (1984) and Reid and MacDonald (1986) presented evidence that V. germanica and V. maculifrons foragers are attracted to meat volatiles from a distance. Unlike the situation with heptyl butyrate and related attractants, the basis for attraction seems clear for meat volatiles, and one expects that one or a few components will be identified which are attractive to most of the scavenging species of yellowjackets. The next step of identifying the actual attractive components from the materials in meats has not yet been completed.

Aldrich et al. (1985), however, did identify individual components from a different source which are attractive to yellowjackets. They found (E)-2-hexenal and linalool to be attractive to V. maculifrons foragers from a distance of approximately 50 cm. (E)-2-hexenal and linalool are released from damaged leaves, and Aldrich et al. (1985) suggest that foraging wasps use plant chemicals released in response to feeding to find herbivorous insect prey.

Yellowjacket pheromones might also be a potential aid in control, but this topic has received relatively little attention. Akre (1982) summarized most of the information on yellowjacket pheromones. Queen, mating, alarm, sex, aggregation, and pupal warming pheromones have been proposed, although in no case has a thorough bioassay and identification been performed. Recently, Maschwitz (1984) has proposed an alarm pheromone for Dolichovespula saxonica which is the same or similar to that earlier proposed for Vespula vulgaris. Dioxaspiro[4.5]decanes have been described as "repellents" or "aggression inhibitors" or "anti-aggregative" pheromones of Vespula vulgaris (for example: Doherty, 1984; Mori and Ikunaka, 1984) after the appearance of Francke et al. (1978). Unfortunately, more effort has been spent on the synthesis of these compounds than on the characterization of their biological activity and additional studies are necessary to evaluate the true effect, if any, of these materials.

MacDonald et al. (1976) suggested that more detailed investigations of yellowjacket behavior, life history, physiology and biochemistry were needed before control of foragers would be feasible. Their suggestion has generally been followed, and recent research has attempted to elucidate more basic aspects of yellowjacket behavior and biology. Foraging behavior has a direct influence on how baits are found and utilized, and has been investigated from several directions. Temperature has long been known to affect yellowjacket foraging (reviews in Spradbery, 1973; Edwards, 1980). Most previous papers have correlated ambient temperature with activity at the nest entrance. Milani (1982), however, measured body temperatures of V. germanica as well as ambient temperature and discussed how thermoregulation was accomplished. Heinrich (1984) measured thoracic temperatures of D. maculata and V. vulgaris workers and found that D. maculata maintains its thoracic temperature more consistently than does V. vulgaris. Heinrich suggested that this may be correlated with the foraging methods of these wasps, D. maculata capturing live prey, and V. vulgaris scavenging. D. arenaria would be an interesting wasp to examine in this context, as its body size is similar to V. vulgaris, but its food habits are more similar to D. maculata.

Sharp and James (1979) found that Vespula squamosa foragers were attracted to yellow in preference to other colors. V. vulgaris (Real, 1981) and V. germanica (Beier, 1984) were also shown to prefer yellow to blue. V. germanica use yellow and black striped patterns to find other wasps at food sources (Parrish and Fowler, 1983; Beier, 1984). V. maculifrons (Parrish and Fowler, 1983) and V. vulgaris (Lyubarskiy et al., 1983) however, apparently do not. Yellowjackets can learn the location of food sources and will make several trips to a good source. They more readily use less variable food sources, even when the total food available is the same (Real, 1981).

Another area of yellowjacket behavior focused on in recent research has been the study of nesting biology in yellowjackets, investigating nest structure, composition, location, and associates. MacDonald et al. (1974) is an example of one of the initial studies of this sort. To date, most of the yellowjacket species of the United States have had their nesting biology studied, either individually (see reviews mentioned above; also: MacDonald et al., 1980; Yamane et al., 1980a; MacDonald and Matthews, 1981; Akre et al., 1982; Reed and Akre, 1983a; MacDonald and Matthews, 1984; Akre and Bleicher, 1985), or as communities (Roush and Akre, 1978; Keyel, 1982). Similar data are available for European species of yellowjackets (reviewed in Spradbery, 1973; Edwards, 1980) and are becoming available for Asian species (for example: Takamizawa, 1981; Makino, 1982).

Most of the information on nesting biology has been covered in the reviews mentioned previously and has not changed appreciably with the addition of new species. Colony sizes, locations, and durations vary with geography and among the major taxonomic groups of yellowjackets. Variation within a taxonomic group seems to be less than among taxonomic groups, but noticeable differences exist among species. For example, species of Dolichovespula typically have moderate sized colonies which end in late summer or early fall. The nests are usually exposed and hang from the branches of trees or the eaves of buildings. However, nests of D. arenaria have been found in a wide variety of locations including wall voids, car seats, and in subterranean sites, while D. maculata is found in a much narrower range of sites, preferring branches and eaves (Greene et al., 1976; Roush and Akre, 1978; Keyel, 1982).

Species of the Vespula rufa species group (an american name corresponding to the subgenus Vespula (Vespula) of Guiglia, 1972, and to the genus Vespula s.s. of Bluthgen, 1961) make small to moderate sized colonies which also end in late summer or early fall. Their colonies are usually subterranean. Species of the Vespula vulgaris species group (subgenus Vespula (Paravespula) of Guiglia, 1972; genus Paravespula of Bluthgen, 1961) make large colonies which are active until late in the fall, occasionally into winter. These species also seem more likely to form perennial colonies (Akre and Reed, 1981a; Ross and Matthews, 1982). Colonies of these species are typically subterranean, although V. germanica seemed to nest primarily in structures in the United States (Morse et al., 1977; Keyel, 1982). V. germanica appears to be "rediscovering" a subterranean nesting habit as it moves west, however (MacDonald and Akre, 1984).

The systematics of yellowjackets has continued to be an active area, especially as more asian species are studied (Yamane et al., 1980b; Archer, 1980, 1982; Eck, 1980, 1984; Varvio-Aho, 1984). As more taxonomic and behavioral/ecological information becomes available, finer and finer distinctions among species are appearing. The relative importance of these distinctions has not yet been completely elucidated, however.

The wealth of numerical data on colony characteristics, besides being useful for comparison with taxonomic information, has been used to generate mathematical models of colony growth and population densities. Long et al. (1979) used linear regression to model various aspects of V. pensylvanica colony size. Archer (1981) presented a considerably more complicated simulation model of colony growth for V. vulgaris and D. sylvestris, while Greene (1984) used data from yellowjackets to test previously published theories of worker and queen production schedules in social insects. Keyel (1982) used multiple regression to assess the effect of various nest site and habitat variables on colony growth for several species. Several of the habitat variables measured appeared to affect species distributions and abundances. Pallett (1984) found that D. maculata and D. arenaria tended to nest in the same locations year after year and Lord and Roth (1985) showed the same for V. maculifrons. Lord and Roth (1985) also suggested that yellowjacket colony success is related to the habitat.

In addition to models of individual colony growth, a number of models of population growth have been proposed or supported. Akre and Reed (1981b) and Madden (1981) provide additional correlation of yellowjacket densities with low levels of spring rainfall, thus supporting the hypothesis of Beirne (1944). Pallett (1984) found that weather-related bird predation was a significant cause of failure in young Dolichvespula arenaria and D. maculata colonies.

Archer (1985) combined summer and autumn weather effects with queen usurpation and queen quality to explain yellowjacket population densities and, in particular, proposed 2 year and possibly 7 year cycles in density. In trying to explain population density cycles as a result of cylcles in individual quality, Archer (1985) is invoking an hypothesis previously proposed by Chitty (1958) to explain population density cycles of small mammals. Usurpation of young colonies by queens is common and has been suggested as a density influencing factor previously (Matthews and Matthews, 1979; MacDonald and Matthews, 1981; MacDonald and Matthews, 1984). Usurpation can occur both facultatively as in V. squamosa and V. flavopilosa, or obligately as in D. arctica and V. austriaca. In most species, invading queens appear to be aggressive, attacking the host queen (Reed and Akre, 1983b), although in certain circumstances, and in most circumstances for D. arctica (Greene et al., 1978) , the invading queen is passive, and coexists with the host. More and more is becoming known about queen behavior, both in regard to mating (Ross, 1983a; Post, 1980) and the critical early period of nest initiation and early development (Ross et al., 1981; Matthews et al., 1982; Ross, 1983b).

Madden (1981) supported yet another possible density influencing factor by demonstrating correlations of V. germanica density with the abundance of blowfly populations. MacDonald et al. (1980) and Roush and Akre (1978) also noted indications that populations are affected by food availability. Aggression at food sources appears to be common among foraging yellowjackets (Parrish and Fowler, 1983; Keyel, 1982; Parrish, 1984; Pflumm, 1984) and suggests the possibility that food is influencing population dynamics.

Almost all support for the hypotheses of population dynamics stated above comes from correlation data. Actual experimental tests manipulating the levels of prey or carbohydrates, changing habitat characteristics or queen densities are necessary to establish causation and to distinguish the relative importance of the different factors. In addition, it is not necessarily true that all these hypotheses are mutally exclusive. All of the factors may be important and the relative importance may change. More experimentation is needed to understand the conditions under which these factors and others operate. This type of information is necessary to know how to break the yellowjacket life cycle and achieve control.

Yellowjackets will no doubt continue as urban pests. In fact, they will probably increase their conflict with people. In common with other urban pests, yellowjackets live well in association with people. Many yellowjacket species thrive in the habitats that man favors and have used human vehicles to reach new areas far beyond their normal range (Edwards, 1976). V. vulgaris has become established in New Zealand (Donovan, 1984) in addition to V. germanica. D. maculata has also recently been captured from New Zealand (Harris, 1984). V. germanica continues to spread to other countries in the world (Giganti, 1983; Willink, 1980) and throughout the United States (MacDonald and Akre, 1984). Considering the adaptability of these wasps and the amount of international travel, it is likely that yellowjackets, especially species of Vespula (Paravespula), will continue to expand their ranges to various parts of the world. In doing so, yellowjackets will continue to be model organisms for the study of questions on the behavioral ecology of social insects. They will also continue to provide a challenge for the development of control techniques.

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INDUSTRY RESEARCH PRIORITIES AND FUNDING

George W. Rambo, Ph.D., R.P.E.
National Pest Control Association
8100 Oak Street
Dunn Loring, Virginia 22027

The first National Conference on Urban Entomology has brought to the forefront the importance of the many disciplines involved in urban entomological research. This research, in the past and on into the future, will be the basis for developing control programs for many of the urban pests.

The pest control industry, with estimated income of over 2.8 billion dollars, has survived to this day primarily based on the use of pesticides to accomplish its goal of protecting the nation's health and property. The future development or, if you will, sophistication of the pest control industry lies in the incorporation of your research into the business of pest control. Also we must educate the public as to the importance of our industry and your research.

The pest control industry has grown as has the science of urban entomology. Similar to your discipline, our industry too struggles for recognition. You heard an excellent synopsis of this in Dr. William Robinson's presentation on the perspective of urban entomology. You have also been presented with information on topics that show the basics of insect behavior and biology, and that opens the door to altering biology for control. Some information is not new but offers the base for developing new strategies for future pest control services.

The pest control industry is concerned about the future of your discipline. We encourage research, and are pursuing ways to increase funding. Before we discuss these, it is best to review priorities we see as a need for the pest control industry.

One priority, which is not necessarily a research one but a need for the researchers, is cooperation. As with most scientific research, there is ultimately a need to move to the field to apply, in this case, those concepts learned in the lab. Also, much of the information we need, as an industry, is not found in the lab but in the urban areas in which we work. It is of the utmost importance that we, the PCO, cooperate and work with the researcher, gain mutual respect for each other's disciplines and learn how to apply what we learn.

Our industry's control concerns lie in several areas. In an open letter to both the Agriculture Research Service (ARS) and the Cooperative State Research Service (CSRS), the National Pest Control Association (NPCA) listed areas we would consider **priority research areas**. These are:

- **Resistance** - We know there is resistance to many of our pesticides present in rats, mice, fleas, cockroaches and stored product pests. In some cases, researchers have noticed behavioral and morphological changes in resistant cockroaches. This needs further research since, at present, it is just a good topic for heated discussions.

  In addition, the resistance studies must look into the future. What new "pesticides" are being developed and will, or how fast will, insects or vertebrates become resistant to these new compounds? This type of planning is not much different than plant breeding programs for resistance to rusts. The economics are not too far afield either, since we lose hundreds of millions of dollars in stored products every year due to infestations of resistant pests.

- **Pheromones** - The interest in this field has increased a hundred fold in the last few years. More and more pheromones, IGR's and attractants have been isolated, synthesized, and found their way and acceptance into the urban pest control usage.

  This is an indication of change and of need. The reliance on the traditional pesticides to control pest problems has been shaken. New methodologies have to be developed to train personnel and implement such materials into control programs. In addition, resistance factors have to be looked at for these compounds.

  Field research with pheromone attractants should be performed to relate pest infestation size to trap counts. This would give us a realistic picture of pest dynamics, economic losses and less use of pesticides.

- **Pest Management** - Although this term is, I believe, overworked, there is still a need to explain these concepts and to demonstrate the use in effective control programs. I do not believe that success has been demonstrated in urban pest control for this concept.

  At present, only the Army and some other EPA funded programs have utilized, or tried to utilize, pest management concepts in controlling some of our domestic pests. Unfortunately, the monies spent are wasted because the results are not visible as published data or for public utilization. Research funded through USDA/ARS can reach the U.S.D.A. Extension Service and be utilized in consumer information.

An example of such research could be in flea control: the homeowner judges the flea problem based on the dog or cat scratching. Many times the fleas are **not** present in populations that would bother the homeowner. In many more cases, information to the homeowner on the more specific habits of fleas, weather conditions that favor flea development and how to actually survey for such problems would stop many unnecessary applications of pesticides. Some of this research has been done, some is still ongoing, in fact, at the ARS Gainesville lab. We would urge pest management research in areas of flea control, stored product pests, vertebrate control and cockroach control.

- **Development of Control Strategies** - This may appear to be a part of the above concept but in actuality it combines all of the previous areas. This also requires the most work because it is field work. Laboratory studies tells us what to look for, not what will happen in the actual control situation.

  In the area of stored products, this concept is an absolute must at this time. The loss of our liquid fumigants have resulted in the increased use of other pesticides - just to protect against, not necessarily to eliminate, an infestation. In some cases, the increased use is alarming. The controller is using higher concentrations and more frequent applications of pesticides. In the present "activist society," we, government and industry, can ill afford the publicity surrounding such programs.

  Only through research can we demonstrate effective programs. These programs may increase costs to producers or consumers but they will lead to a less concerned public and a more respected image for both researcher and professional.

I feel this best summarizes our needs and the direction we feel USDA/ARS and CSRS should be considering in funding continuing research programs. Because of the needs and increasingly rapid changes, we urge more monies be channeled into such research.

This is all well and good. The industry is and will be continuing to lobby for such research programs and will continue to encourage developments in this area. However, we all know these ideas and goals go nowhere without funding.

For an industry with over $2.8 billion a year in income, an industry without which people would suffer from disease, property destruction and food loses, the amount of monies given to this research is appalling. An agricultural industry providing less to the economy than us receives millions of dollars in research monies. As pointed out earlier in our conference, there is over 14.5 million dollars devoted to research in the tobacco industry - and the health concerns there are well documented - why can't the government agencies divert some of this to development of programs that would study the effectivess of pest management programs for various pests and consumer educational information for the extension services to use?

The pest control industry has taken steps to try to fund various projects in urban entomology. The National Pest Control Association has a research fund - the Phil Spear Research Fund - that is slowly building, that will eventually be used to fund research at the universities supporting urban entomology research. At present, NPCA allocates $30,000 a year to various research projects. Over the past few years we have supported studies in flea control, resistance studies, Formosan termites, pesticide residue studies and wood destroying beetle work. This fund has also contributed to the establishment of a chair in urban entomology at Texas A&M and a new research facility at the Virginia Polytechnic Institute and State University.

These support grants are minute as to what is needed. However, individual state pest control associations have come to the aid of several researchers; South Carolina, Louisiana, Kansas, Texas, Maryland, Virginia, North Carolina are among the state pest control associations that donate monies to research within their state entomologists. In the future, it is NPCA's goal to increase this funding and work closely with the states and researchers to accomplish this.

Federal monies are difficult to acquire. NPCA will continue to work and lobby for funds to be released, or rather reallocated, to research projects that will benefit the research community.

Our goal is to have various state associations lobby their representatives to put pressure on the appropriate agencies to provide monies. It is our hope that researchers will not become discouraged in this endeavor and will continue to pursue funding from all the sources discussed here.

Our future lies in the organization of a strong working group to pursue the funding of urban entomology. NPCA supports the formation of an urban entomology work group. We will pursue this end with our membership and contacts in the research field.

FLEAS

Michael K. Rust
Department of Entomology
University of California
Riverside, CA 92521-0314

The order Siphonaptera probably arose from a Mecoptera-like ancestor in the Upper Cretaceous Period, less than 100 million years ago, coinciding with the evolution of mammals in the Triassic Period and the birds in the Jurassic Period (Rothschild 1975). It is this beginning of the nesting and burrowing microhabitat that has contributed much to the evolution of the fleas. By 50 million years ago, the order Siphonaptera was very much like it is today. Of the 2237 described species as of 1969, less than a dozen have been widely reported as urban pests and only a few species pose a serious medical or veterinary problem. About 94% of the described species feed on mammals, the remaining 6% feed on birds. The vast majority of the species (ca. 74%) are associated with rodents, highlighting the importance of the nest and burrow microhabitat. Larval developmental requirements of high relative humidities and warm temperatures and nutritional requirements of undigested blood produced by adult fleas feeding on the host have reinforced this dependence to the burrow or nest habitats and specific microhabitats.

Although the oriental rat flea, Xenospylla cheopis (Rothschild), has attracted considerable attention throughout history because of its involvement as a vector of plague, surveys of urban domestic animals in Egypt (Amin 1966), Europe (Kristensen et al. 1978), India (Joseph 1981) and the United States (Amin 1976, Osbrink and Rust 1985) clearly indicate that members of the genus Ctenocephalides, dog and cat fleas, are the most important domiciliary species worldwide. In a survey of fleas associated with Norway rats, ground squirrels, and cottontail rabbits, Ryckman (1971) found that only the sticktight flea, Echidnophaga gallinacea (Westwood), was found on all three hosts. The other six species of flea were limited to a single host species. Fortunately, the flea Diamanus montanus (Baker), an important vector of sylvatic plague in ground squirrels, was very selective. Otherwise, our control problems with plague in the western United States would be compounded. Only a few species such as the cat flea, Ctenocephalides felis (Bouché), have extensive lists of hosts. The cat flea has been collected on numerous hosts including domestic cats and dogs, mongoose, several mustelids, oppossum, sheep, cattle, horses, and a number of rodents (Hopkins and Rothschild 1966).

In the past, our control and research efforts have focused on the use of various insecticides and growth regulators applied to indoor and outdoor areas likely to harbor adult and immature fleas. Instead of reviewing our past successes and failures with this approach to flea management, I would like to discuss some concepts and possible research avenues involving host-parasite interactions that might prove successful in pest management. Marshall (1981) in his informative text on the ecology of ectoparasitic insects writes, "Although on man and his domestic animals populations of ectoparasites may reach high levels, on wild hosts populations are generally low, kept thus by host activities such as grooming and perhaps by an immunological response. Indeed the occasional large population on a wild host is usually a symptom of ill-health and not the cause of it."

Should we consider infestations on dogs and cats as wild or domestic population? What are typical population levels on domestic animals? Secondly, do host activities such as grooming have an impact on cat flea populations? What mechanisms are responsible for the initiation of host grooming? Is there evidence of an immunological response in our domestic pets to ectoparasites? Can these natural responses be exploited in pest management programs? Let us examine what is known in regards to cat fleas and their relationship with cats and dogs.

The cat flea, C. felis, is a magnificent ectoparasite highly adapted to exploit a mobile host such as the cat or dog. Unlike most rodent and bird fleas, the adults remain on the host where feeding, mating and oviposition occur. Many of the hosts of the cat flea do not live in burrows or nests and consequently the adult flea cannot depend upon the host routinely returning to the same location. The large spines on the tibia and femur and the pronotal combs assist the cat flea in remaining attached to the host. Amin and Wagner (1983) have shown that there is a significant correlation in the gap between the teeth of the pronotal comb and the diameter of the host's hair. For example, the spacing in the teeth of male and female C. felis is 35 ± 6.57 µm and 38 ± 5.45 µm, respectively, matching the diameter of the hairs on the head (35 ± 17.86 µm) and the dorsum (38 ± 20.66 µm) of Felis catus. Obviously an important adaption for those species that need to remain attached to the host.

Within 1 to 2 days after mating, the female begins depositing ca. 300 µm long opalescent eggs that are broadcast onto carpets, bedding, and other substrates frequented by the host. Eggs hatch in about 2-3 days. Table 1 shows that the larvae require a source of blood to develop and in the absence of dried blood they die. In nature the blood is provided in the form of dried fecal droplets of blood excreted by adult fleas feeding on the host. In C. felis orientis Jordan, Joseph (1976) determined that adult females consume ca. 18% and males consume ca. 33% of their weight in blood in a 3-7 minute feeding bout. During the feeding, the adult fleas defecate 8-10 droplets of blood which dry and fall from the host along with flea eggs. Consequently, only areas where the pet frequents will have sufficient amounts of fecal blood to permit larval development, an evolutionary link to the burrowing habitat of rodent fleas.

If the host can successfully curtail or limit adult flea feeding, there are two distinct consequences. First the nutritional intake required by females to lay batches of eggs will be severely limited. Secondly, the large volume of blood required for larval development will be interrupted preventing new generations of parasites.

The stage of the flea life cycle that is the most resilient to environmental factors and control procedures is the pre-emerged adult within the pupal cocoon. Once the flea becomes a pre-emerged adult, it is no longer as susceptible as the egg and larva are to desiccation or exposure to flucuating temperatures (Silverman and Rust 1985). Laboratory studies have also shown that this stage is not vulnerable to most contact insecticide sprays. Consequently, the pre-emerged adult is the most troublesome stage to control and failure to kill this stage results in retreatments.

Table 1. Development of *C. felis* from egg stage in various rearing media.

	Cocoons		Adult emergence[b/]		
Media mixture[a/]	% formed	Range %	Unforced %	Total %	Range %
Chow, Wheast, Difco blood	77	65-85	44	74	60-85
Media used once	82	80-85	28	69	60-75
Chow + Wheast + blood albumen	78	70-80	43	64	35-80
Dog Chow	0	0	0	0	0
Wheast	0	0	0	0	0
Dog Chow + Wheast (12%)	0	0	0	0	0
Chow + blood albumen (17%)	73	70-80	46	66	40-85
Wheast + blood albumen (60%)	75	50-100	25	70	40-100
Blood albumen	68	55-80	6	67	55-80

[a/] Regular media - chow, wheast, dry blood (7.5:1:1.5, by wt.). Most mixed ingredients used at proportions similar to those in regular media, mixed 1:4 with sand. Maintained 12/23/83 to 1/23/84 at 25.5°C.

[b/] Based on 5 replicates, each begun with 20 eggs. Unforced emergence - live and dead fleas emerged spontaneously. Total emergence - unforced + adults liberated from cocoons while submerged in tepid water.

Osbrink and Rust (1985), in surveys of cats collected at a local shelter over a two-year period, found that cats had low levels of infestation during the winter. In the spring the level and percentage of cats infested significantly increased. Environmental factors had an impact on flea abundance. Of the factors examined, temperature showed the highest correlation to flea numbers. The average number of fleas per cat was 9.6. However, of the 701 cats examined 377 did not have any fleas. In fact, most cats had relatively few fleas. Surveys in Kenya indicated that 52% of the hares were infested with an average of 2.3 *C. felis* per host (Flux 1972). Haas (1966) found averages of 2.4 to 4.6 *C. felis* per male mongoose and 1.3 to 1.7 *C. felis* per female mongoose. Younger mongooses had significantly more fleas than did adults. Similarly, cats weighing <1.8 Kg, considered to be juvenile, had 17.7 fleas per cat whereas older cats averaged only 4.7 fleas (Osbrink and Rust 1985). In general, surveys suggest that the usually low number of cat fleas per host is in accordance with Marshall's thoughts about populations of ectoparasites on wild hosts. The data suggests that host grooming activities and immunological responses may be operating in domestic animals such as cats and dogs resulting in low parasite infestation levels.

One approach to protecting the host from ectoparasites has been the use of polyvinylchloride resin collars impregnated with insecticides as shown in Table 2. Fox et al. (1969a,b) showed greater than 90% reductions for at least 14 weeks in the production of adults from trays of eggs collected from underneath cats wearing dichlorvos collars against DDT, dieldrin, and malathion resistant fleas. Olsen (1984) reported some limited activity of propoxur impregnated collars. Collars used for 3 to 6 weeks before testing were not effective. If we consider the intrinsic contact activity of various insecticides against adult cat fleas, the concept of a flea collar providing a lethal dose of insecticide to surface of the pet seems suspect. The LD 50's for a 24-hour exposure of the organophosphates, chlorpyrifos and diazinon, applied to cotton cloth are about 0.002 and 0.15 $\mu g/cm^2$, respectively. The carbamates, propoxur and bendiocarb, are 4.5 and 1.6 $\mu g/cm^2$, respectively. The pyrethroids, fenvalerate and permethrin, are 11.9 and 12.4 $\mu g/cm^2$, respectively. In fact, Olsen (1984) reported that permethrin and pyrethrum collars were ineffectual. It is unlikely that most of these materials incorporated into a collar could provide enough toxicant on the fur to provide kill of adult fleas. Fisch et al. (1977) reported that plasma and erythrocyte cholinesterase of dogs with propoxur collars was lower for up to 3 days. Possibly small levels of insecticide in the blood may contribute to lower egg production and reduction of adult fleas on hosts with propoxur or dichlorvos collars.

Table 2. Tests with polyvinylchloride resin collars impregnated with insecticides against cat fleas on cats and dogs.

Toxicant	Cat or dog	Residual activity (weeks)	Reference
DDVP	c	9	Fox et al. 1969a,b
Naled	c,d	0	Olsen 1984; Randell et al. 1980
Permethrin	c	0	Olsen 1984
Propoxur	c,d	3,1	Olsen 1984; Randell et al. 1980
Pyrethrum	c	0	Olsen 1984
Temephos	d	1	Randell et al. 1980

One exciting recent development is the incorporation of the insect growth regulator, methoprene, into shampoos to treat the animal. Olsen (1985) reported that shampoos containing methoprene result in decreased viability of eggs produced by adult fleas on treated hosts. There was no effect against adult fleas but over 90% of the eggs did not hatch. Brief exposures of the eggs less than 48 hours old on treated filter paper inhibited hatching.

In series of experiments with guinea pigs exposed to cat fleas, Feingold, Benjamini and co-workers developed a classic chart regarding the sequence of host reactivity to insect bites (Feingold et al. 1968). Guinea pigs were exposed daily to cat fleas and after 10 days exposed twice daily for the next several months. Their findings are summarized in Table 3. For up to four days after being exposed to fleas (Stage I), there was no response whatsoever. Stage I is frequently referred to as the induction period. From days 5 to 9 or Stage II, there were delayed skin reactions. In Stage III there were both delayed and immediate skin reactions. The delayed skin reactions are believed to be cell mediated responses to low molecular components found in the saliva of the flea. This component must bind with collagen molecules in the skin to initiate the response. The immediate reactions observed in Stages III and IV are believed to be humoral antibodies. After 90 days the animal becomes hyposensitive, no longer responding to the feeding of the flea. The evolutionary significance of the delayed and immediate reactions is evident. As the animal is subsequently attacked, the host's skin responds and the irritation initiates grooming. This intensive grooming in most rodents prohibits us from utilizing them as hosts for cat fleas. In some situations the intense grooming leads to secondary infections and the classic cases of flea bite dermatitis. In fact, surveys have shown that heavily infested cats and dogs often show the fifth stage or classic hyposensitivity (Feingold et al. 1968).

Table 3. The sequence of reactivity of hosts to insect bites proposed by Feingold et al. (1968).

Stage	Characteristics	Duration (days)
I	No observable skin reactions	0-4
II	Delayed skin reactions	5-9
III	Immediate skin reactions followed by delayed skin reactions	9-60
IV	Immediate skin reactions	60-90
V	No reactivity	>90

If mice infested with the Anopluran Polyplax were prevented from grooming, the initial populations of lice grew rapidly (Bell et al. 1966).

However, after a period of time the populations of lice declined and the surviving mice were parasite free. They found that the rate of the development of this acquired host resistance was directly proportional to the level of infestation and that it was localized. An excellent review by Nelsen et al. (1977) covers many aspects of this acquired host resistance. Recent studies by Chiera et al. (1985) with the African cattle ear tick, Rhipicephalus appendiculatus Neumann, showed that if any stage of this 3-host tick fed on a resistant host, egg production was reduced by 98%. Over the years, we have noticed similar trends on the animals that we use for rearing cat fleas. Table 4 shows the egg production of two cats infested with 20 adult male and female cat fleas. Initially fleas on the resistant cat produced about 225 eggs per day, but this number quickly declined and within 14 days only 50 eggs were being produced. We have repeatedly experienced this decline in flea egg production in older cats and subsequently use only young cats for our production. The biochemical nature of the acquired host resistance is unknown.

Table 4. Production of flea eggs from two laboratory cats.

	Number of flea eggs collected on day							
Cats	2	4	7	10	13	16	19	21
Susceptible	250	310	210	350	238	325	167	167
Resistant	225	230	167	190	50	135	51	51

a/ Twenty adult male and female cat fleas were put on each cat.

In summary, not all attempts to protect the host from adult fleas have proven successful. However, the mechanisms and factors that initiate the development of hyposensitivity and acquired host resistance to fleas and other ectoparasites are an extremely promising area for future research and a potential tool in pest management.

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NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

February 24-27, 1986

Center for Adult Education
University of Maryland
College Park, MD

PROGRAM

Monday, February 24, 1986

Evening
8:00 - 10:00 p.m. ... Mixer

Tuesday, February 25, 1986

Monday

8:00 a.m. ... Registration .... Main Lobby

9:00 a.m. ... Morning Session .... Auditorium

Moderator - Gary Bennett, Purdue Univ.
Local Arrangements - Gene Wood, Univ. of Maryland
Welcome - Allen Steinhauer, Univ. of Maryland
Robert Riley, CSRS, USDA

9:25 a.m. ... Introductory Comments .... Auditorium
Pat Zungoli, Clemson Univ.

9:45 a.m. ... A Perspective of Urban Entomology ....
William Robinson, VPI & SU

10:30 a.m. ... Break .... Main Lobby

11:00 a.m. ... Insecticide Resistance and .... Auditorium
Pest Management Strategies
F. W. Plapp, Texas A&M Univ.

Noon ... Luncheon .... Chesapeake and Ft. McHenry Rooms

1:00 p.m. ... Afternoon Session .... Auditorium
Moderator - Phil Hamman, Texas A&M Univ.

1:00 p.m. ... Insecticide Residues .... Auditorium
Jim Ballard, Dow Chemical Co.

1:30 p.m. ... Formosan Subterranean Termites .... Auditorium
Nan-Yao Su, Univ. of Florida

2:00 p.m. ... Outdoor Species of Cockroaches .... Auditorium
Art Appel, Auburn Univ.

2:30 p.m. ... Subterranean Termites .... Auditorium
Jeff La Fage, Louisiana State Univ.

3:00 p.m. ... Break .... Main Lobby

3:30 p.m. ... Concurrent Discussion Sessions
Insecticide Residues .... Room 1105
Roger Gold, Univ. of Nebraska - Moderator
Presenters
Jim Ballard, Dow Chemical Company
Ross Leidy, North Carolina State Univ.

Outdoor Species of Cockroaches .... Room 0123
Coby Shal, Rutgers Univ. - Moderator
Presenters
Eric Benson, Clemson Univ.
Ellen Thoms, VPI & SU
Richard Brenner, USDA, Gainesville
Art Appel, Auburn Univ.

Subterranean Termites .... Room 1123
Raymond Beal, US Forest Service - Moderator
Presenters
Joe Mauldin, US Forest Service
Glenn Esenther, US Forest Service
Mike Rust, U.C. Riverside
Margaret Collins, Smithsonian Institution

4:30 p.m. ... Repeat of Concurrent Discussion Sessions

Insecticide Residues .... Room 1105

Outdoor Cockroach Species .... Room 0123

Subterranean Termites .... Room 1123
Raymond Beal, US Forest Service - Moderator
Presenters
Charles Wright, North Carolina State Univ.
Ken Grace, U.C. Berkeley
Jeff La Fage, Louisiana State Univ.
Nan-Yao Su, Univ. of Florida

5:30 p.m. ... Adjourn

Wednesday, February 26, 1986

8:30 a.m. ... Morning Session .... Auditorium
Moderator - Claude Thomas, B&G Equipment Co.

8:30 a.m. ... Insect Growth Regulators .... Auditorium
Gerardus Staal, Zoecon Corp.

9:00 a.m. ... Insect Pheromones .... Auditorium
William Bell, Univ. of Kansas

9:30 a.m. ... Old House Borer .... Auditorium
William Robinson, VPI&SU

10:00 a.m. ... Break .... Main Lobby

10:30 a.m. ... Concurrent Discussion Sessions
Insect Growth Regulators .... Room 1123
Gary Bennett, Purdue Univ. - Moderator
Presenters
Richard Patterson, USDA, Gainesville
Jim Yonker, Purdue Univ.
Gerardus Staal, Zoecon Corp.

Insect Pheromones .... Room 1105
Ted Shapas, American Cyanimid - Moderator
Presenters
Jerome Klun, USDA, Beltsville
William Bell, Univ. of Kansas
Coby Schal, Rutgers Univ.

Wood Boring Beetles .... Room 0123
Harry Moore, N.C. State Univ. - Moderator
Presenters
Doug Mampe, D. M. Associate
William Robinson, VPI & SU

11:15 a.m. ... Repeat of Concurrent Discussion Sessions

Insect Growth Regulators .... Room 1123

Insect Pheromones .... Room 1105

Wood Boring Beetles .... Room 0123

Noon ... Luncheon .... Chesapeake and
Ft. McHenry Rooms

1:00 p.m. ... Afternoon Session .... Auditorium
Moderator - George Rambo, NPCA

1:00 p.m. ... Behavior and Biology of
German Cockroaches .... Auditorium
Don Reierson, U. C. Riverside

1:30 p.m. ... Insecticide Resistance .... Auditorium
Don Cochran, VPI&SU

2:00 p.m. ... Behavior and Biology of Yellowjackets ..... Auditorium
Richard Keyel, S.C. Johnson & Son

2:30 p.m. ... Break .... Main Lobby

3:00 p.m. ... Concurrent Discussion Sessions

German Cockroaches .... Room 123

Phil Koehler, Univ. of Florida - Moderator

Presenters

Mary Ross, VPI&SU

John Owens, S.C. Johnson & Sons

Don Reierson, U.C. Riverside

Insecticide Resistance .... Room 0123

Gene Wood, Univ. of Missouri - Moderator

Presenters

Roger Gold, Univ. of Nebraska

Don Cochran, VPI&SU

F. William Plapp, Texas A&M Univ.

Yellowjacket and Other Hymenoptera ..... Room 1105

Jay Nixon, American Pest Management - Moderator

Presenters

Al Greene, Univ. of Maryland

Roger Akre, Washington State Univ.

Richard Keyel, S.C. Johnson & Sons

4:00 p.m. ... Repeat of Concurrent Discussion Sessions

5:00 p.m. ... Adjourn

6:00 p.m. ... Reception and Cash Bar .... Chesapeake and Ft. McHenry Rooms

7:00 p.m. ... Banquet .... Chesapeake and Ft. McHenry Rooms

Master of Ceremonies - Gene Wood, Univ. of Maryland

Banquet Speaker - John Osmun, Purdue Univ.

"Pests, Pesticides, People and Progress"

Awards Presented To:

Dr. Walter Ebeling and Dr. James Grayson

Thursday, February 27, 1986

9:00 a.m. ... Morning Session .... Auditorium

Moderator - Eric Smith, Orkin

9:00 a.m. ... Industry Research Priorities and Funding... Auditorium

George Rambo, NPCA

9:30 a.m. ... Fleas .... Auditorium

Mike Rust, U.C. Riverside

10:15 a.m. ... Closing Comments .... Auditorium

Pat Zungoli, Clemson Univ.

10:30 a.m. ... Adjourn

LIST OF REGISTRANTS

David Adams - P.O. Box 368
Lebanon NJ 08833

Roger D. Akre - Department of Entomology Washington State Univ.
Pullman WA 99164

Linda Ameroso - Cornell Cooperative Ext. 100 Clinton St., 2nd fl.
Brooklyn NY 11201

Arthur G. Appel - Department of Zoo.-Ent.
Auburn Univ. AL 36849-4201

James B. Ballard - Dow Chemical 505 South Lenola Rd.
Moorestown NJ 08057

Riccardo Balzarotti - Endura Spa Villae Pietrmellara 5
40121 Bologna ITALY

Stephen Barcay - 227 S. River Rd.
W. Lafayette IN 47406

Ernest C. Bay - West. Wash. Res. & Ext. Center 7612 Pioneer Way, East
Puyallup WA 98371

Raymond H. Beal - Southern Forest Exp. Stn. P.O. Box 2008, GMF
Gulfport MS 39505

James N. Bean - Rt. 1, Box 1313
Davis CA 95616

William J. Bell - Dept. of Entomology University of Kansas
Lawrence KS 66045

Gary W. Bennett - Dept. of Entomology Purdue University
West Lafayette IN 47907

Eric P. Benson - Dept. of Entomology Clemson University
Clemson SC 29634-0365

Jonathan Berger - 3568 Tree Court Industrial Blvd.
St. Louis MO 63122

Judy Bertholf - One Galleria Tower 13355 Noel Rd, Suite 1025
Dallas TX 75240-6604

Donald N. Bieman - 1800 NW 4th St., D31
Gainesville FL 32609

Dale Blaine - PCO Services LTD 232 Norseman St.
Toronto, Ontario Can M8Z 2R4

Jim Blasius - No-Tox Products, Inc. 50 North 41st Ave.
Phoenix AZ 85009

Chris Bowley - Rentokil Inc 3567 Bigelow Blvd.
Pittsburgh PA 15213

Ralph A. Bram - USDA-ARS Building 005
Beltsville MD 20705

Dale Bray - c/o APM, Inc. 170 W. Main St.
Elkton MD 21921

Richard J. Brenner - USDA-ARS P.O. Box 14565
Gainesville FL 32604

Brian L. Bret - Western Pest Control 907 State St.
Princeton NJ 08540

Beverly S. Brewer - 17360 Coit Rd.
Dallas TX 75252

J. Thomas Bridges - MAAH AGro Chemicals P.O. Box
Vero Beach FL 32962

Bill Broome - 3568 Tree Ct. Ind. Blvd.
St. Louis MO 63122

Cheryl Bryant - Lehn & Fink Products 7 Mercedes Drive
Montvale NJ 07645

Jerry Bukovsky - Terminix International, Inc. 3 A Nashua Court
Baltimore MD 21221

Ed Butler - Aerosol Services Co., Inc. 425 So. Ninth Avenue
City of Industry CA 91746

David Byron - Entomology Department Virginia Tech
Blacksburg VA 24061

Douglas Calsetta - Lehn & Fink Products 7 Mercedes Drive
Montvale NJ 07645

D. Michael Chambers - Department of Entomology Clemson University
Clemson SC 29634-0365

John Chapman - 855 Ridge Lake Blvd.
Memphis TN 38119

Christian M. Christensen - S 225 Agri Sci Ctr, N Univ. of Kentucky
Lexington KY 40546

Patricia P. Cobb - 205 Extension Hall
Auburn University AL 36830

Phil Cobb - Terminix International, Inc. Suite 402, 51 Monroe St.
Rockville MD 20850

D. G. Cochran - Department of Entomology VPI & SU
Blacksburg VA 24061

Michael J. Colangelo - P. O. Box 220
Atco NJ 08004

Pat Copps - PCO Services LTD 232 Norseman ST
Toronto, Ontario Can M8Z 2R4

Terry Couch - 7781 NW 73rd Ct
Miami Springs FL 33166

William E. Currie - P. O. Box 2547
Arlington VA 22202

Danny L. Davis - 212 E. Susquehanna Ave
Towson MD 21204

Carol DiSalvo - Ntl Park Serv, Ctr Urban Ec 1100 Ohio Drive, SW
Washington DC 20242

Ed Diselrod - 2920 Vassar Rd.
Livonia MI 48152

Ronny Dodson - Department of Entomology VPI & SU
Blacksburg VA 24061

Maureen Duffy - City of Gaithersburg 31 South Summit Avenue
Gaithersburg MD 20877

Gene Dupree - N.C. State University Entomology Dept, Box 7613
Raleigh NC 27695-7613

Walter Ebeling - 10659 Rochester Ave.
Los Angeles CA 90024

Samia El-Touny - 2932 Ligon St, Apt. 8
Raleigh NC 27607

Glenn Esenther - 5162 Barton Road
Madison WI 53711

Robert Esworthy - 4815 South 31st Street #C-1
Arlington VA 22206

Sandra R. Evans - USAEHA, ATTN: PMPMD
Aber Prov Grd MD 21010-5422

Brad Filson - 158 Mt. Olivet Ave
Newark NJ 07114

Peter J. Fitzgerald - Pestkill Ltd. Box 1720 Grand Cayman
British West Indies

Wayne Foster - Witt Pest Control 3351 Bigelow Blvd.
Pittsburgh PA 15219

James F. Fowler - 4019 Brookhill Road
Baltimore MD 21215

Austin M. Frishman - 30 Miller Rd.
Farmingdale NY 11735

Gil Gilroy - PCO Services Ltd 232 Norseman St.
Toronto, Ontario Can M8Z 2R4

Roger E. Gold - 101 NRH Univ of Nebraska
Lincoln NE 68583-0818

J. R. Gorham - FDA HFF 237 200 C Street, SW
Washington DC 20204

J. Kenneth Grace - Univ. California - Entomology 218 Wellman Hall
Berkeley CA 94720

Nancy Z. Gray - 855 N. Edison St.
Arlington VA 22205

James McD. Grayson - 1300 Oak Drive
Blacksburg VA 24060

Stanley G. Green - 143 Wellington Drive
Warminster PA 15229

Walter R. Gusciora - 18 Maple Drive
Jamesburg NJ 08831

Ann M. Gutierrez - Dow Chemical Company 505 S. Lenola Road
Moorestown NJ 08057

Arnold D. Gutman - Stauffer Chemical Co. 1200 S. 47th Street
Richmond CA 94804

R. G. Haines - The PLM Companies P.O. Box 733
Orange Park FL 32067-0733

John H. Hainze - MS 167; SC Johnson & Son, Inc. 1525 Howe St
Racine WI 53402

Frances Hamburg - Dow Chemical, Inc. 315 W. Meadow Brook
Midland MI 48640

Robert Hamilton - Cook College - Entomology P. O. Box 231
New Brunswick NJ 08903

Philip J. Hamman - Entomology Dept. Texas A & M Univ
College Station TX 77843

James Harmon - Dept. of Entomology VPI & SU
Blacksburg VA 24060

Barbara B. Harris - 855 N. Edison St.
Arlington VA 22205

Joseph K. Harris - 295 Cumberland
Memphis TN 38112

R. C. Hillmann - Box 7613 N.C.S.U.
Raleigh NC 27695-7613

Motokazu Hirao - Hirao Biological Institute 1765-147 KITA
Shizuoka JAPAN

Paul E. Hoch - 368 Tharp Dr
Moraga CA 94556

Diana M. Horne - 10030 Lake Occoquan Drive
Manassas VA 22111

Patricia Hottel - 1012 W. Lunt
Schaumburg IL 60193

Robert G. Howe - Dow Chemical Company P.O. Box 1706
Midland MI 48640

Harry N. Howell - Dept. of Entomology Texas A & M University
College Station TX 77843

Herb Jacobi - 1300 Symons Hall Department of Entomology
College Park MD 20742

Steve Johnson - Dow Chemical Company, Inc. P.O. Box 1706
Midland MI 48640

David W. Jones - 1655 Whitlock Road
Marietta GA 30066

Kevin S. Jordan - Department of Entomology Clemson University
Clemson SC 29634-0365

Paul M. Kaercher - P. O. Box 373
Smyrna DE 19977

Harry L. Katz - Berkshire E 3076
Deerfield Beach FL 33442

Anne R. Keller - 5841 Banning Place
Burke VA 22015

Robert Kelly - Fertilizer Inspection & Anal. 206 Federal Building
Spartanburg SC 29301

Ken Kendall - Lloyd Pest Control 935 Sherman St
San Diego CA 92110

Richard E. Keyel - S.C. Johnson & Son, Inc. 1525 Howe Street
Racine WI 53042

M. Ayn Keyes - P.O. Box 75075
Oklahoma City OK 73147

Roger C. Keyes - P.O. Box 75075
Oklahoma City OK 73147

Stephen Kincaid - Navy Facilities Eng. Command 407 W. Mantua
Wenonah NJ 08090

Carolyn Klass - Entomology, Comstock Hall Cornell University
Ithaca NY 14853

Leon P. Knight - Technical Products Corp 1501 London Blvd.
Portsmouth VA 23704

Martin A. Knight - Hill-Smith Termite Control 1780 Bartlett Rd.
Memphis TN 38134

Philip G. Koehler - 214 Newell Hall University of Florida
Gainesville FL 32611

William A. Kolbe - Western Industries 475 Prospect Ave.
West Orange NJ 07052

Sandra Kraft - Pinto & Associates 914 Hillcrest Dr.
Vienna VA 22180

Charles Kramer - 1300 Symons Hall Department of Entomology
College Park MD 20742

Jack Kramer - ICI Americas, Inc. P. O. Box 208
Goldboro NC 27530

Philip G. Kreer - APM Inc. 170 W. Main St.
Elkton MD 21921

Jeffrey P. La Fage - 325 Chippenham Dr.
Baton Rouge LA 70808

Mark Lacey - Terminix International 228 Philadelphis Pike
Wilmington DE 19809

John E. Lane, Jr. - 5444 Sands Rd.
Lothian MD 20711

Michael James Lanton - Western Exterminator Company 1732 Kaiser Avenue
Irvine CA 92714

Paul Leck - 102 S. Belleview Avenue
Langhorne PA 19047

Lisa A. Lemke - Dept. of Entomology Clemson University
Clemson SC 29634-0365

Donald R. Lewis - 103 Insectary Iowa State Univ.
Ames IA 50011

Kenneth R. Lewis - Union Carbide T. W. Alexander Drive
RTP NC 27709

Dorette Lund - Terminix International 401 Parkway Drive
Broomall PA 19908

William Lyon - Ohio State University 1735 Neil Avenue
Columbus OH 43210

Doug Mampe - D. M. Associates 33 Mann Ct
Monmouth Beach NJ 07750

Joseph T. Mares - Mobay Corporation 17745 S. Metcalf Ave.
Stilwell KS 66085

Stephen Marken - 142 Cambridge Street
Charleston MA 02129

Joe K. Mauldin - P.O. Box 2008 GMF
Gulfport MS 39505

David F. McCormick - Dow Chemical USA 8002 Discovery Dr
Richmond VA 23288

Michael McGowen - Velsicol Chemical Co 341 E. Ottio St
Chicago IL 60634

Roger W. Meola - Dept of Entomology Texas A & M University
College Station TX 77843

Doug Miller - Terminix Int'l, Suite 1204 940 W Valley Rd.
Wayne PA 19087

Jerry Mix - 7500 Old Oak Boulevard
Cleveland OH 44130

Harry B. Moore - Entomology Dept., Box 7613 N.C. State University
Raleigh NC 27695

Gordon R. Nielsen - 217 Hills Bldg., UVM
Burlington VT 05405-0082

<u>Jay Nixon</u> - American Pest Management 5201 1st Place NE
Washington DC 20011

<u>Neil Ogg</u> - Dept. of Entomology 256 Poole Ag. Center
Clemson SC 29634-0394

<u>Tim O'Grady</u> - PCO Services Ltd 232 Norseman St.
Toronto, Ontario Can M8Z 2R4

<u>J. K. Olson</u> - Dept. of Entomology Texas A & M University
College Station TX 77843

<u>John M. Owens</u> - SC Johnson & Son, Inc. 1525 Howe St.
Racine WI 53403

<u>Judith L. Page</u> - Dow Chemical Box 1706
Midland MI 48640

<u>Richard S. Patterson</u> - USDA-ARS P.O. Box 14565
Gainesville FL 32604

<u>Hal Paul</u> - Box 4913
Kansas City MO 64120

<u>Lawrence J. Pinto</u> - Pinto & Associates 914 Hillcrest Drive
Vierna VA 22180

<u>David Pitts</u> - 440 E. Walwithe
Philadelphia PA 19144

<u>F. William Plapp</u> - Dept. of Entomology Texas A & M University
College Station TX 77843

<u>Salvotore W. Porcellini</u> - P.O. Box 1032
Forked River NJ 08731

<u>James C. Porter</u> - Rose Exterminator 3950 Falls Road
Baltimore MD 21211

<u>Alan L. Postlethwaite</u> - Conserv. Analy. Lab Smithson. Inst.
Washington DC 20560

<u>Thomas Preve</u> - New England Pest Control 161 O'Connell St.
Providence RI 02905

<u>Diane G. Probus</u> - Prince William Forest Park P.O. Box 209
Triangle VA 22172

<u>John E. Proctor</u> - Mobay Chemical Corporation 8400 Hawthorn Road
Kansas City MO 64120

<u>David O. Quinn, Ext. Spec.</u> - W. VA Univ. P.O. Box 6057, 408 Brooks
Morgantown WV 26506-6057

Edgar M. Raffensperger - Entomology - Cornell Univ.
Ithaca NY 14853

George Rambo - NPCA 8100 Oak Street
Dunn Loring VA 22027

John B. Randall - Biology Center M.S. 401 SC Johnson & Sons, Inc.
Racine WI 53403

George J. Raymond - NOR-AM Chemical Co. P.O. Box 7495
Wilmington DE 19803

Jos. J. Reardon, Sr. - 2207 N. Assau
Wilmington DE 19809

Byron L. Reid - Dept. of Entomology Purdue University
W. Lafayette IN 47907

Donald Reierson - Department of Entomology University of California
Riverside CA 92521

John Rightor - Dept. of Entomology VPI & SU
Blacksburg VA 24061

Robert C. Riley - 5013 West Cedar Lane
Bethesda MD 20814

William H Robinson - Dept. of Entomology VP1&SU
Blacksburg VA 24061

Richard B. Rogers - Dow Chemical 2400 Longfellow Lane
Midland MI 48640

Steven E. Rogosheske - 8810 Tenth Avenue North
Minneapolis MN 55427

Ken Rose - Dow Chemical, Inc. 205 Hollybrook
Midland MI 48640

Mary H. Ross - Dept. of Entomology VIP & SU
Blacksburg VA 24061

Robert W. Rummel - Western Termite & Pest Control 10843 Main St.
Fairfax VA 22030

Michael K. Rust - Dept. of Entomology UC-Riverside
Riverside CA 92521

Jack Ryder - Dow Chemical, Suite 2005 20 Perimeter Center, East
Atlanta GA 30346

Bruce Ryser - Pet Chemical, Inc. 7781 NW 73rd Court
Miami Springs FL 33166

R. S. Saini - Department of Biology
Tuskegee Univ. AL 36088

Joseph E. Savage - Cooperative Extension 1425 Old Country Road
Plainview NY 11803

Ron Sbragia - Dow Chemical USA 2800 Mitchell Drive
Walnut Creek CA 94598

Coby Schal - Dept of Entomology Rutgers Univ., Cook Clg
New Brunswick NJ 08903

Brian M. Schneider - Entomology Hall Purdue Univ.
W. Lafayette IN 47907

David E. Schneider - Velsicol Chemical Corp. 341 E. Ohio Street
Chicago IL 60611

Mohammad Shadab - Amer. Mus. Nat. Hist. Ent. 79 Street
CPW NY 10024

Ted Shapas - American Cyanamid 697 Route 46
Clifton NJ 07015

Robert D. Sharp - Chempar Products 660 Madison Ave.
New York NY 10021

Tim Showalter - Witt Pest Control 3351 Bigelow Blvd.
Pgh. PA 15219

Charles Silcox - American Oil and Supply Int'l 8th & Harrison St.
Frenchtown NJ 08825

Jules Silverman - American Cyanamid Co. Shulton Res Div, Rt. 46
Clifton NJ 07015

Alan Smith - Entomology & Econ. Zool. Cook College
New Brunswick NJ 08903

Eric H. Smith - Orkin National Ser. Dept. 2170 Piedmont Road, NE
Atlanta GA 30324

Louis N. Sorkin, RPE - Am. Mus. of Nat. Hist. 225 E. 46th St, 12-C
New York NY 10017

William J. Spitz - Big State Pest Control P.O. Box 15099
Houston TX 77220

Bernie Spivack - Quaker City Exterminating 955 Locust Avenue
Bensalem PA 19020

Judi Spivack - Quaker City Exterminating 955 Locust Avenue
Bensalem PA 19020

Reid Sprenkel - Dow Chemical 20 Perimeter Ctr. E. 2005
Atlanta GA 30346

Michelle Sprint - Pesticides, DCRA 5010 Overlook Ave, SW
Washington DC 20032

Forrest E. St. Aubin - Penick Bio-UCLAF Corp. 1050 Wall Street West
Lyndhurst NJ 07070

Gerardus B. Staal - Zoecon Corporation 975 California
Palo Alto CA 94303

Ken Stein - 196 W. 11th Ave., #309
Columbus OH 43210

Daniel M. Stout - 3568 Tree Court Ind. Blvd.
St. Louis MO 63122

Nan-Yao Su - Univ. of Florida 3205 College Ave.
Ft. Lauderdale FL 33324

John J. Suarez - NPCA 8100 Oak Street
Dunn Loring VA 22027

Amy Suggars - Box 7613
Raleigh NC 27695-7613

Theodore W. Suman - Science Division Anne Arundel Comm. Clg.
Arnold MD 21012

W. Wayne Surles - Nor-Am Chemical Co. P.O. Box 7495
Wilmington DE 19803

Claude Thomas - B & G Equipment Co. P.O. Box 130
Plumsteadville PA 18949

Ellen Thoms - Department of Entomology Virginia Tech
Blacksburg VA 24061

Vern E. Toblan - NOR-Am Chemical 3509 Silverside Road
Wilmington DE 19803

William Todaro - 1727 Blvd of the Allies
Pittsburgh PA 15219

Robin G. Todd - Insect Control Research 1330 Dillon Heights Ave.
Baltimore MD 21228

Jeffrey Tucker, R.P.E. - P.O. Box 70375
Houston TX 77270

Douglas VanGundy - Zoecon Industries 12200 Denton
Dallas TX 75234

Leslie Vissage - Pee Dee Experiment Station P.O. Box 271
Florence SC 29503-0271

Richard C. Whitman - Whitman Exterminating Co. 601 S. Oakwood Ave.
Beckley WV 25801

Harry E. Williams - University of Tennessee P.O. Box 1071
Knoxville TN 37901

Rusty Wilson - 1725 N Main St, Suite 105
Summerville SC 29483

Jeffrey J. Winegar - 53 North Main St.
Pennington NJ 08534

James H. Wojciak - MAAA Agro Chemicals P.O. Box X
Vero Beach FL 32962

Gene Wood - 1300 Symons Hall Department of Entomology
College Park MD 20742

Charles G. Wright - P.O. Box 7613-NCSU
Raleigh NC 27695

Julian R. Yates, III - Dept. of Entomology, U of HI 3050 Maile Way
Honolulu HI 96822

James Yonker - Entom Department Purdue University
W. Lafayette IN 47907

Brian Zeichner - PMPMD, AEHA
Aber Prov Grd MD 21010-5422

Patricia A. Zungoli - Clemson University Entomology Department
Clemson SC 29634-0365

Acknowledgments

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American Cyanamid
B. & D. A. Weisburger, Inc.
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