Proceedings of the National Conference on Urban Entomology

1988

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DEDICATION

We dedicate these proceedings to the memory of Arnold Mallis.

ARNOLD MALLIS

Arnold Mallis was born October 15, 1910, in New York City, where he attended elementary schools and William Cullen Bryant High School. In 1927, his family moved to Hollywood, California, and Arnold graduated from high school in 1928. He entered the University of Southern California with the intention of studying dentistry. Hard times of The Depression forced Arnold to drop out of college to work as a shipping clerk in a dress factory. From 1930-1932 Arnold took a two-year Forestry course in Pasadena Junior College, then entered the University of California at Berkeley and earned a B.S. in Entomology in 1934. Graduate work at the University of California, Berkeley and Davis, and part-time employment, resulted in an M.S. in entomology in 1939.

In 1936 Arnold became licensed as a professional pest control operator, and from 1936 to 1938 he worked as a pest control operator. From 1939 to 1942 he was an entomologist for the Building and Grounds Department at UCLA. In 1942 and 1943 he was with USPHS working on malaria control in Louisiana. In 1944 he held a Hercules Fellowship in entomology at the University of Delaware; and from 1945 to 1968 he was senior research entomologist with the Gulf Oil Company. In 1968 Arnold joined the Department of Entomology at Pennsylvania State University. He retired in 1975.

As a scientist Arnold Mallis is recognized for his research on household insect pests. He published more than 20 research papers during his career. In the pest control industry, Arnold is best known for his *Handbook of Pest Control*, which appeared in first edition in 1945; later editions included 1954, 1960, 1969, and 1982.

Arnold is recognized and remembered as a generous, modest, thoughtful man. He was genuinely interested in the professional pest control operator, and entomologists working with the pest control industry. As an urban entomologist, Arnold blended the art and the science of pest control, and set an example for those that followed. He had a wealth of knowledge about household and structural insect pests - and willingly shared it. His status in the industry was unmatched, and equal to his merit.

NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

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URBAN ENTOMOLOGY PERSPECTIVES

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In the two years since the last Conference much has happened in urban entomology--there have been some accomplishments, and some setbacks. Jeff LaFage and I will review the current status of this discipline in the United States by presenting data and our own perspective on specific topics. Jeff will discuss the financial base for research in urban entomology, and comment on undergraduate education. I will address the current status of the discipline, some important issues, and some of the major accomplishments.

Accomplishments:

There have been some significant achievements since the last Conference.

[] Formal Conference on Urban Entomology provided by the Entomological Society of America.

During the 1986 meeting of the Entomological Society of America, Pat Zungoli's requested to meet with the Governing Board to discuss providing a formal conference on urban entomology at the national ESA meeting. Accompanying and supporting Pat when she met with the Board were many urban entomologists. Either through fear or foresight the Governing Board granted formal conference status to Urban Entomology. The first Conference, 1987 in Boston MA, was organized by Darryl Sanders (Univ. Missouri). Roger Gold (Univ. Nebraska) will provide leadership to the Conference at the 1988 meeting in Louisville, KY.

While it is important that we have achieved this status, I think we should not plateau here. Formal conferences do not run themselves; the urban entomology community will have to provide leadership for and participation in the conference if we are to keep it a part of the ESA program. I encourage you to support the conference by submitting papers under the Urban Entomology heading.

[] Urban entomology included as one of the potential funding categories for the Northeast Region and the Southern Region IPM Grant funds.

Many of us have been frustrated at the lack of opportunites for urban entomologists to secure funds from federal sources. Pat Zungoli (Clemson Univ.) pointed out this problem to one of the people associated with the Southern Region IPM Grant funds. The result of Pat's letter and help from Ron Kuhr at North Carolina State University, the supported in this category, and it could be argued that it was a shallow victory--it is a start. They can not continue to deny the importance of this discipline in the southern region--or any other region!

Coby Schal has worked to secure recognition for the urban category in the Northeast Region. In 1987 he was successful in convincing the Directors of the Northeast Region to include an "urban" category and support funds. He was successful, and several entomologists will receive funding.

[] The Entomology Department at Texas A & M has announced they are accepting applications for the endowed Chair for urban entomology; and construction of the Urban Pest Control Research Center Va Tech is complete and the building is operational.

Academic positions in this discipline are not common in entomology departments in the U.S. In fact, some of the positions in existance now did not begin with the label "urban entomologist"--but simple acquired it over time. The endowed Chair at Texas A & M will help with the visibility and recognition of urban entomology--especially in such a strong agricultural state like Texas. The Urban Pest Control Research Center at Virginia Polytechnic Institute and State University is an example of what the professional pest control industry can do when it becomes as organized--the industry can raise $300,000 in two years, get a university to donate land a some equipment, and build a modern research facility.

[] The 2nd National Conference on Urban Entomology.

It is no accident that the first national conference was successful, and no small accomplishment that there was even greater interest in the second conference. The three hundred scientists gathered here will exchange ideas and data, and help urban entomology become recognized at the national and international level. There are firm plans to continue this Conference on the 2-year schedule, and the next meeting will be held in 1990.

<u>*Perspectives*</u>:

I would like to offer my perspective on some issues important to urban entomology.

[] National Conference on Urban Entomology.

I think this National Conference has done much to solidify the discipline and increase communication between academia and industry, students and faculty, and research and practice. The interest and increased participation in the Conference this year is evidence of the value of the format and the theme. But there are now doubts expressed as to the need for this Conference to continue, and questions about how well this Conference serves academia and industry.

Does the formal conference on Urban Entomology at ESA meetings relieve the need to have a separate national meeting?

I think not. I think that the two "conferences" serve separate goals. We are a distinct and growing discipline, to scatter our efforts and our papers throughout the ESA meetings was as inconvienent as it was insulting. We now have the recognition of our society, but more important we have most of the pertinent papers centered in one formal conference. There is certainly the opportunity to attend and listen to other papers at our annual meeting, and most of us take that opportunity during the hectic 3-4 days. But this also the opportunity to stay close to one room and one conference and learn of the research in urban entomology.

The National Conference on Urban Entomology--this meeting--was intended to provide some important things to our discipline. The original intentions were to bring together the people working in urban entomology from academia--extension, teaching, research--government, and industry for an exchange of ideas and research data. As you know, there is limited participation of industry in the ESA meetings, but keen interest in this meeting. The Steering Committee has worked to maintain an informal, informative atmosphere here. We have tried to eliminate the labels of industry and academia, we have not allowed any commercial displays or booths, and do not allow picture taking or tape recording of presentations without prior permission from the speaker. The goal was to provide for the exchange of information and ideas between scientists, and not to worry about the escape of unpublished data. This meeting provides all of us the opportunity to focus on our discipline, and the people that work in it, for a few days every two years.

Some have expressed the idea that this National Conference serves the chemical and professional pest control industry very well--perhaps too well, and that academia is simply providing another training session in household and structural insect pests. I don't think that is a fair assessment. Academia is represented here, as well as industry, and we all have something to offer. I think this Conference serves us all very well. I want to express my firm support and expectations that it will continue.

[ ] International Conference on Urban Entomology, and the consideration of a Journal of Urban and Public Health Entomology

As this discipline is becoming better established and represented at ESA meetings and by this Conference, it may be time to consider a separate journal. I propose that we seriously consider the organization of a Journal of Urban and Public Health Entomology. There are urban entomologists working around the world, and the results of their applied and basic research is scattered in numerous scientific and industry journals. I think a journal that gathered together this research data would appeal to the worldwide audience of scientists and pest control professionals. There are industry trade journals that in a limited serve this function, but they do not serve the scientific community in transferring data.

Certainly, the initiation of a new journal further isolates the scientists involved--concentrating the specialists even further. The decision to establish the journal will take time to carefully assess the need and potential support. This should be a major topic at the 3rd National Conference on Urban Entomology in 1990.

URBAN PEST MANAGEMENT

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This paper discusses what I believe constitutes urban pest management programs and some of the elements that do not. It also addresses some problems that face urban IPM as a discipline and practice, and discusses elements of IPM programs I have solicited from colleagues and the literature. Finally, I present the results of an urban IPM program that was developed and implemented at the National Institutes of Health at Bethesda, Maryland.

As I investigated this subject I was presented with suggestions that could not be included as elements of IPM programs. For instance it was suggested that IPM was the use of all pest control methodology. Or that target specific or well-timed pesticide applications or pesticides less environmentally disruptive, represented IPM. Or the use of pheromones, IGRs, models and other more precise control techniques legitimize the use of the term IPM. In fact these are illustrations of what by themselves cannot justify being called an Integrated Pest Management program.

So what is IPM, and why are urban pest management programs not flourishing? Of the many definitions of IPM, some of them cite economy, environmental soundness, integration of disciplines, systems approaches, systems analysis, systems management --- words that encompass broad fields of thought but more often they refer to fields of corn or soybeans. IPM started and was nurtured in a mixture of agriculture, ecology, and biological control where it was debated, criticized, analyzed, fought over, and like most of our national trends and customs, finally exported to the rest of the country from its birthplace--California! Agricultural IPM was then studied and developed by some of the brightest minds working in the natural sciences, especially entomology. This all came about at the same time as the ecology reformation and the initial period of environmental consciousness. A movement with the momentum that IPM had is be bound to be hell on the acts that followed, and urban pest management happens to be one of those acts. This implies differences between agricultural and urban PM and there must be some differences or urban PM would have advanced abreast of agricultural PM. We can all identify a few differences, and one that comes to my mind immediately is the development of thresholds. Quantifying pests and crop loss seems an obvious sequence but, how do we count pest numbers and economic loss in urban areas. In the first place accurately counting pests as secretive as cockroaches and rodents, key urban pests, is nearly impossible given the current state of urban PM technology. And secondly if we had counts, how would we quantify the economic loss caused by a cockroach infestation in an apartment. The frustration that results from these obstacles has led to counting dollars saved on pesticide reduction as a measure of program success. We also have many surveys that tell us of the need to reduce urban pests and which provide us with estimates of how much people would be willing to spend to be rid of certain pests. Agricultural research in IPM can show a specific economic advantage for keeping pests below a certain quantity while the need for much urban pest reduction is driven by aesthetics, personal values, community norms or legal or regulatory pressure--none of which are easily quantified. So here is a major tenant of pest management: the establishment of thresholds; and we cannot yet scientifically establish them or evaluate them in economic terms. We have to accommodate this establishment of thresholds in some way.

That brings up another difference in agriculture and urban PM. That of the lack of an adequate research data base. The paucity of urban pest basic research data in the decades of the 50s and 60s is now being torturously accumulated by a population of scientists, most of whom are in this relatively small audience. On the other hand, it would take many auditoriums to hold agricultural researchers in entomology, pathology, agronomy and other IPM disciplines. We are underfunded and undervalued ironically in a time of urban growth that is about to take another leap in the next decade. I won't dwell more on this because I feel our time has come, and the future of urban pest research is gaining a full head of steam. Witness this second Urban Entomology Conference and, our professional societies which are burgeoning with urban papers and symposia, and the increasing interest of students. Private industry involved in the production of urban pest control products for professionals and consumers is increasing its activity and state governments are being pressured by an urban population that wants answers to pest problems and environmentalists concerned as to what those answers might be.

In agriculture, IPM has been broadly applied and accepted. How can we gain this acceptance with urban IPM? First let's look at some IPM principals that are generally accepted in the literature and by colleagues.

One principal is that "Potentially Harmful Pests will Continue to Exist at Tolerable Levels." This means that pest species will likely still be present where IPM is practiced. This statement makes my colleagues in the pest control industry stare in disbelief. It remains, however, that pest eradication or elimination is just not a principle of IPM. One thing this means is simply that IPM, at this time, may not be a desirable method of pest control in all situations. I will talk about that later but I may as well address the term pest elimination now. Earlier I mentioned that we cannot accurately estimate the number of pests--cockroaches for example--to be able to quantify an economic or an action threshold. How then can we know that we have eliminated the roaches in an apartment or restaurant? I know the client demands that the roaches be gotten rid of. I also know that a pest control operator (PCO) cannot stand up and say "I will not eliminate all of your roaches." But elimination is a marketing term that is used in dealing with clients. Roach elimination is a state of mind that exists after a pest control treatment until small nymphs are seen crawling about the kitchen sink a month or so later. Then it's time for a new elimination. Are those nymphs introduced in the proverbial grocery bag or beer case, or are they really just foragers who have been content to remain in the less stressful harborage of a kitchen where most of the population was killed, but not eliminated, by a pest control treatment? We do not easily introduce German cockroaches in the majority of our detached homes even where pesticides are seldom if ever used. Small numbers of roaches are often brought home by those of us who work in areas of large cockroach populations and yet they do not persist or colonize in our homes unless large numbers are brought in. For pest management programs, where roaches are temporarily out of sight I suggest we use the term "non-detectable level" and not elimination. For a sales term "elimination" can be used, but it isn't a PM goal. Goals must be attainable.

Another IPM principal is "The Ecosystem is the Management Unit." To recapitulate my understanding of some terms of ecology, individuals of the same species exist as a population. Different populations exist together in a community and a community with its physical and biotic factors constitutes an ecosystem. A kitchen or an apartment can be an ecosystem. The ecosystem is not the pest population, the pest population is part of the ecosystem. Too often we lapse into regarding a pest population as the management unit. When we do we lose sight of all the factors that keep pest populations at a tolerable level. Using the ecosystem as the management unit we can manipulate each system differently and design our program accordingly. The corollary here is that pest management is site specific. Each management unit can be different.

In urban pest management we should consider all pest populations in the community, but not all need be considered equally. We automatically work with key pests. These are pests which recur at regular and fairly predictable intervals. These are the focal organisms for a pest management program and we devise schemes to manipulate the environment thereby reducing the key pests equilibrium position to a long-lasting reduced level (tolerable level). Modifying a key pest's environment in an urban ecosystem by reducing its breeding, feeding, and shelter habitat might also influence non-key pests. For instance the effects of sanitation or moisture reduction on cockroaches will also effect populations of ants and silverfish.

What are other necessary elements in an IPM program?

Monitoring. Monitoring is a term that I use because it is historically identified with IPM. It means surveying or inspection. Regular monitoring allows for ongoing surveillance of the system. Monitoring is not only for counting or picking out pest harborage, but for reviewing the management of the ecosystem and noting where changes should be made. As monitoring progresses, thresholds are considered. One method of monitoring or inspection is to divide the system into zones. Zones of potential infestation may be monitored with traps, and then close visual inspection made within zones where infestations are indicated and where thresholds are most likely to be exceeded. Monitoring methods in the future might include computer assisted designs where the floor plans are viewed three dimensionally and where monitoring records are entered by down loading data from hand held computers. The data can then be plotted on the building design to get an overall view of the problem.

Records. Records allow for evaluation of the pest management plan. Needed alternations in the system can be better seen from a series of monitoring records. Records are as important as any element in the plan. Records are best set up for each system where unit management differs because of different ownership, tenancy, etc. Records work well when they are included in log books along with safety data sheets, building rules, liaison names, and so on. The log books and records must be available to the client as well as the pest management technicians. Records must be accurate. Exact counts must be noted and specific locations recorded. Common names of pesticides must be used and specific evaluation of the ecosystem recorded. Writing down statements like "room looks good" or, "used Slug-a-Bug 180 in cabinets" is useless. Accurate accounting of the amounts of pesticides used are mandated by law and are invaluable for evaluation. Total time spent helps to evaluate costs. All evaluations should be noted in a manner where they can be followed up at the next monitoring period.

Liaison. The client's contact or liaison person must always be consulted on each arrival for important communications such as changes in the plan and for explanations of any special observations noted in the log book. Follow-up of past evaluations should be routine at this time. The liaison person is the pest management technician's contact with the organization. They are invaluable. They can make things happen or hinder them. They pass on information from other workers which can provide insights not otherwise available. They also take information to other workers which can facilitate the pest management technician's work.

Education. Educating the clientele goes on in individual conversations and in informal meetings, but any occasion should be taken to formally address the clientele group. Formal presentations and demonstrations emphasize the seriousness that is attached to the pest management plan. Informing and educating the clientele group on the pesticides to be used is essential but it takes time, patience, and clear explanation. People often will take the occasion of a meeting with fellow workers present to air beliefs and question practices. These interchanges are extremely important for they allow individuals to express themselves. Suppressing feelings results in lack of cooperation and even active resistance to the program. At these meetings the importance of alternative methods can be explained and the clientele group enlisted for support or for implementing the practices. The technician should get to know the clientele group in order to enlist their aid, but should not get so chummy that he is not able to evaluate them.

Alternative Control Methods. Everyone is always interested in finding out what alternative controls are used by others. We think "how many can there be?" What besides the same old stuff; sanitation, caulking, weather proofing, etc. etc. I'm afraid that we think of alternative methods as we do a pesticide. We want to strike at the pest when we should be manipulating the ecosystem. We look for a single magic bullet that will tip the balance against the pest when we really should remember to analyze the entire system and change or emphasize as many management practices as we can without the thought of finding a thrust to the heart of the pest population. For instance, evaluating the cultural practices of the clientele often identifies practices which promote key pests. New alternative methods (e.g. baits, pheromone traps, repellents) are only beginning to be developed. The use of several alternatives to pesticides obviously leads to the reduction of pesticide use.

Pesticide Use. Pesticides are acknowledged as "the most powerful tool widely available for use in pest management." But a single pesticide used alone in traditional pest control situations seldom gives us the effect that we would like to see. Pesticides can't perform miracles. We broadcast pesticides in urban systems in the same manner that we use them in classical agriculture spray programs. Even the idea of crack and crevice application has not sunk in in urban pest control. At the National Institutes of Health we have stopped the use of preventive applications of pesticides as a general rule. Where cockroaches are key pests, apparently 90% of preventive applications were not useful and their elimination when supported by alternative methods did not affect the pest management plan.

Where we have pesticide use, the clientele's safety must always be considered. Individuals are variably sensitive to any given pesticide and some are extremely so. So are other animals such as pets and laboratory animals. Disregarding the sensitivities individuals have to pesticides is like waving a red flag at a bull.

Now that we have the ingredients of an IPM program who will buy the product? Not everybody by a long shot. To buy into an urban pest management plan the purchaser has to want it. It is not as easy to sell an urban pest management program as it is to sell an agricultural pest management program. In agricultural IPM we can show an economic advantage in the reduced cost of pesticide application and with no reduction in crop sales receipts. This comes about by utilizing natural controls, cultural practices, and other alternative methods and by monitoring so that other controls can be initiated when an action threshold is reached. In urban situations pest reduction is usually not driven by economics. The health of a pet, or of a tree cannot easily be set down in debit and credit columns. We have aesthetic needs for pest reduction and this makes for somewhat soft reasoning when we try to justify urban pest management, especially when it will obviously cost more than a "low bid." An appropriate question concerning pest control expenditures is "which is the most sound fiscal policy: the lower expenditure for inadequate or often no pest reduction--or--a higher expenditure for adequate pest reduction."

Nevertheless, there are those who desire pest management. For instance, some public agencies, hospitals and other health care facilities, and establishments where scheduled spraying in contract after contract has not provided pest reduction. On the other hand, we find places where pest management is not wanted---very low income commercial housing for instance, where cockroaches come with the rent. These are the places where the suppression of pest infestations cannot be a priority. Also, many pest problems are inconsequential and need only a minimum response. So we should relax and recognize that every situation does not call for a full IPM program. Furthermore, there is much more to be done by all of us in developing safer and more efficacious pesticides, better application methods, better training and other support practices to be used in traditional pest control generally practiced by industry and for use by the general public or the consumer.

But to get back to where and how urban pest management can be used, there are numerous facilities, institutions, office buildings, private apartments, good restaurants, and condominiums where people are not satisfied with traditional methods of pest control and can understand and desire a pest management program. The major impediments to delivering a pest management program were identified by the Council on Environmental Quality in 1980 and one impediment was "inadequate pest control contracts." How can contracts be written and contractors selected for quality programs when low bidders, who either underestimate needs or do not intend to meet needs must be selected? There are processes in place to do this.

First: The client must establish a need for an IPM program. The need statement should include the attributes of pest management and the problems with "low ball" spray operations. The need for a level of expertise should also be included.

Second: A request for proposal (RFP) should be written to include the desires of the client and information that the contractors need to add to their experience and abilities so they can write proposals and evaluate costs.

Third: A technical evaluation committee should be set up to judge technical merit. This committee must be trained in IPM principals, in the client's needs and in the legal steps in contracting prescribed by law. The contracting officer should be involved for legal purposes but not as an evaluator. The contracting officer will also provide boilerplate and receive the bids including price, but the price must not be communicated to the technical evaluation committee.

Fourth: Identify the acceptable proposals and the unacceptable proposals based on the RFP. Do not further evaluate unacceptable proposals.

Fifth: After rating proposals, provide guidance for the contracting office to select the best proposal for the price. Use only technical merit for evaluation support.

Sixth: Provide technical oversight from the facility. Oversight provides coordination between the contractor and facility management as well as quality control of the program.

Writing a request for proposal is not an easy task. It must provide information and set limitations and requirements. Some of the elements are:

- An understanding of IPM particularly as it relates to the facility.

- The level of expertise needed must be set. This means expertise of contractor personnel. What personnel should be available? Should the technical supervisor be an entomologist? Justify all personnel selection decisions. Should they be full time personnel or can they be part-time? Should they be certified? How much experience should they have? How do you evaluate these professionals? What kind of training have they had? Is their training verifiable? Interviews are always helpful.

- The needs of the facility must be established, including limitations that must be taken into account (animals, foods, personnel, etc.).

- IPM practices necessary for success should be identified as desired activities and presented as information (e.g. thresholds, monitoring, alteration of habitats, etc.). Do not use word for word requirements. The client must take responsibility for program failure if specific requirements are mandated but are not followed later.

- Methods for communicating and cooperating should be elicited, e.g. the proposal should include need for liaison personnel. The RFP can elicit this by stating that liaison personnel will be provided.

- Training should be provided to clientele. Training can be a requirement and it requires a specific level of expertise.

- Record keeping requirements must be provided for in the RFP, such as log books - but the form should be negotiated to fit the clients needs too.

- References from similar facilities should be required and reviewed.

The proposal written by the contractor should be evaluated on how well the needs of the facility are understood and not by how well the contractor can parrot the RFP. The contractor must demonstrate his understanding of IPM. Resistance to the elements of IPM by the contractor will polarize the situation and set it up for failure.

Oversight of the contractor's plan is essential. Oversight from the facility provides for ongoing evaluation, cooperation, amendments to the program and satisfying special needs and emergencies.

Urban IPM programs can work. An example is one provided to the National Institutes of Health for their animal facilities by an industry pest control contractor. The program in a 27,000 ft^2 building was evaluated. The 4 month period before contracting where traditional scheduled sprays were used was compared with the 4 month period after the IPM program was in effect (Figures 1 and 2). The comparison showed pesticide use was reduced by 90% and German cockroach populations were reduced by over 89% (Table 1).

Figure 1. Pesticide Use in Ounces: Traditional vs IPM (NIH 1987 -- 4 month period)

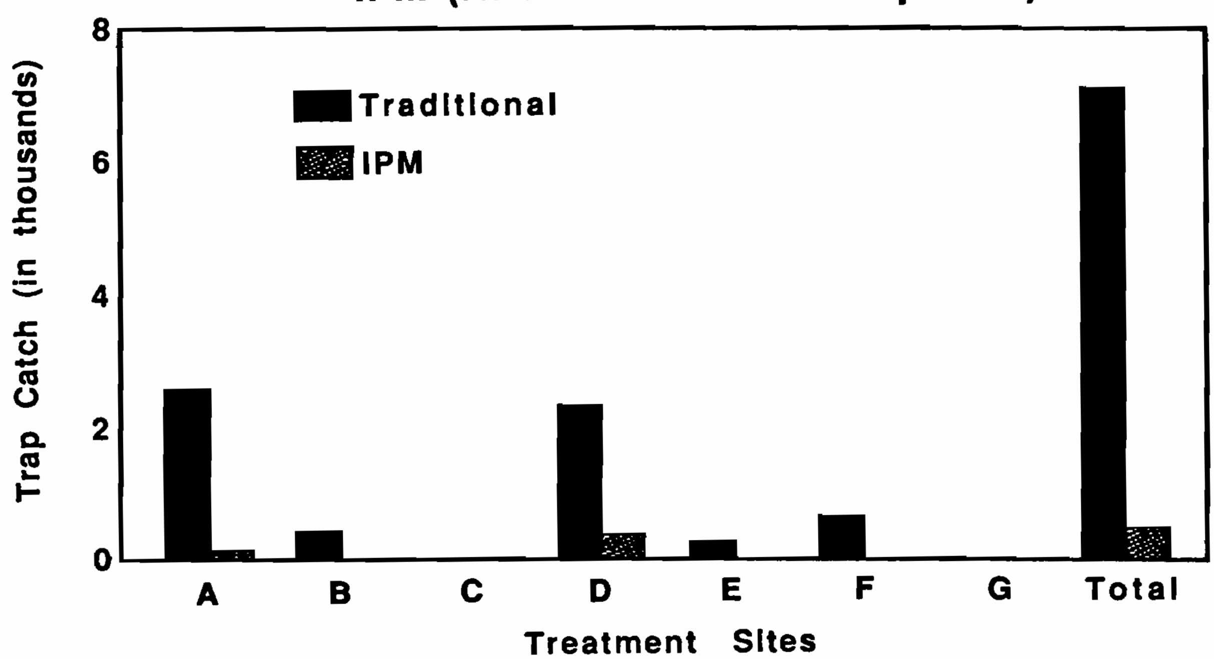

Figure 2. Cockroach Reduction Under the IPM Program (NIH 1987 -- 4 month period)

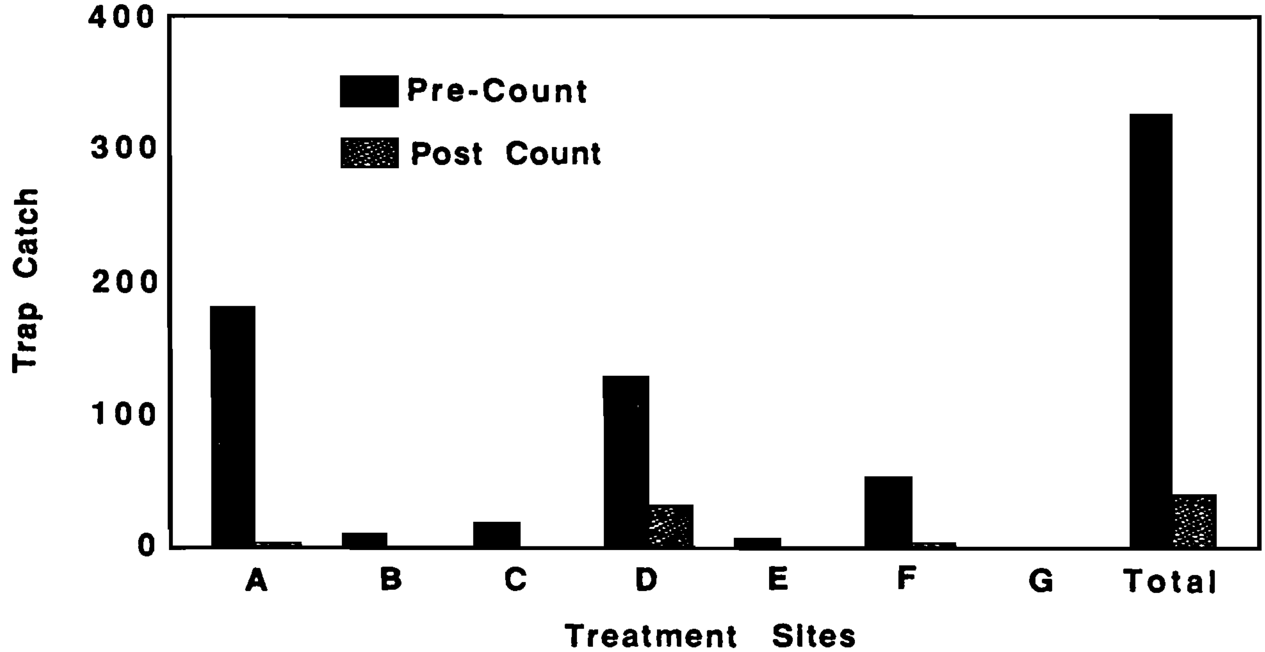

Table 1. Pesticide use (in ounces) and cockroach reduction in a traditional versus an integrated pest management program conducted at the National Institutes of Health. Traditional treatment program evaluation was conducted just prior to implementation of the IPM program. IPM evaluation was conducted four months after program initiation.

	Pesticide Use		Cockroach Trap Count	
Treatment Site	Traditional	IPM	Traditional	IPM
A	2,592	146	178	3
B	416	17	10	0
C	0	4	17	0
D	2,304	359	128	31
E	256	14	8	2
F	640	52	54	6

We believe that a good bit of the pesticide reduction was due to the use of action thresholds. Arbitrary action thresholds which were essential to reducing preventive spraying were set. These thresholds were similar to those used by DOD and the National Park Service and they were arbitrary. They included:

1. an average of 1 cockroach per zone monitoring trap.
2. 1 fresh mouse or rat dropping per room.
3. 1 outside rat burrow or runway in areas regularly used by the facility.
4. any stinging insect nest within reach from the ground.
5. an actual specimen of any pest, e.g., flies, spiders, stored product pests, etc.

Reaching the threshold did not mean the automatic use of pesticides. In some instances it initiated further visual inspections, in others facility protocols were changed.

Evaluation is essential for keeping the program on track, for amending procedures, and for reporting results. The results extended beyond pest reduction, e.g. pesticide safety, and equipment and building repair, improved animal management practices. The program was enthusiastically received by scientists, veterinarians, administrators, and support personnel. Due to the success of this program other facilities at NIH are being put under pest management contract and it has led to inquiries from other institutions around the country.

In conclusion: just because a well thought out program takes place in an urban setting doesn't mean that it is an urban pest management program. In many instances we are still working on the control of pests rather than managing systems. And we are in need of much basic data, new approaches, new methods of all types, and a great deal of experience.

STUDIES ON LYME DISEASE

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In November 1975, the Connecticut State Health Department received two phone calls from mothers whose children had been recently diagnosed as suffering from juvenile rheumatoid arthritis. A diagnosis of juvenile rheumatoid arthritis (JRA) is distressing since it predicts a lifetime of potentially severe arthritis. But what prompted these women to call the health department was the fact that other children in their neighborhoods in Lyme, Connecticut had also been diagnosed with this disease. Normally, JRA affects only one in 100,000 children, yet in one of these families two children and both parents were affected.

The Connecticut State Health Department contacted Allen Steere at Yale University. Steere began an epidemiologic and clinical investigation which localized the outbreak to the three townships of Old Lyme, Lyme and East Haddam, all situated on the east bank of the Connecticut River. The total population was only 12,000, yet 51 people (39 children) were identified with a similar type of arthritis. Even within the affected area the cases were clustered. Patients tended to live in heavily wooded areas rather than town centers. In Old Lyme and East Haddam half of the affected individuals lived on just four roads where 1 in 10 children had arthritis! This could not be juvenile rheumatoid arthritis--it was much too frequent and JRA is not known to occur in clusters. Moreover, 55% of the cases had their onsets during the summer months of June through September, yet in households with more than one affected member, the initial symptoms had usually occurred in different years.

These observations are best explained if the arthritis around Lyme were an infectious disease transmitted not by person to person contact but rather by some other vector like an arthropod. In fact, 25% of this first group of patients remembered having a skin rash one to several weeks before the arthritis began. The rash started as a red papule or bump and gradually expanded to give a bull's eye appearance. Both the patients and their doctors thought the rash had come from an insect bite but only one could remember being bitten, and that had been by a tick. Most of the skin lesions occurred on the trunk or on the limbs near the trunk, locations that are compatible with transmission by a crawling rather than a flying arthropod vector. Based on these unique clinical and epidemiological findings, Steere concluded that he was dealing with a new disease, transmitted by an arthropod and probably caused by a virus. He called the disease Lyme arthritis.

Early this century a Swedish physician described an expanding red skin rash which occurred in Scandinavian patients bitten by a small, hard tick, Ixodes ricinus. He named this rash erythema chronicum migrans (ECM). More intrepid investigators in Europe in the 1950's showed that ECM was an infectious disease by successfully transmitting it to themselves after removing the red border of a patient's rash and implanting it under their own skins. A few days later an expanding red rash appeared. Thus, the rash seemed to be caused by something transmitted by the tick rather than by the tick bite itself. Initially it was suspected that Lyme arthritis and the preceding ECM were caused by an arbovirus transmitted by ticks. Patients' sera were tested for evidence of antibodies specific for 38 known tick transmitted diseases, for 178 other arthropod transmitted viruses, and for other organisms including leptospires. Joint fluids were cultured for bacteria and mycoplasmas. Not one of the tests was positive.

Was there a tick in Connecticut that could be the vector of Lyme arthritis? In an epidemiologic study done in 1977, 9 of 43 ECM patients remembered tick bites at the site where ECM formed, and one of them saved the implicated tick which was identified as Ixodes scapularis, a tick closely related to Ixodes ricinus. It was soon discovered that this tick was a new species now called Ixodes dammini or the deer tick. When deer and small mammals were trapped on the shores of the Connecticut River and ticks collected from them, there were approximately equal numbers of the common dog tick, Dermacentor variabilis, on both sides of the river; but there were 12 times as many Ixodes dammini on the east side where the clusters of Lyme arthritis cases had occurred. Thus, this tick became implicated in the spread of Lyme arthritis.

The search for the infectious agent transmitted by the tick and responsible for ECM and Lyme arthritis was carried out on both sides of the Atlantic. A bacterium was the most likely candidate since it was known that European ECM could be treated with penicillin. In 1976 the New York State Department of Health began epidemiological studies on Long Island to investigate the increasing incidence of Rocky Mountain spotted fever, a rickettsial disease transmitted to humans by Dermacentor variabilis. In the fall of 1981 there was a fatal case of Rocky Mountain spotted fever on Long Island. Adult Dermacentor variabilis are not found in the autumn, but adult Ixodes dammini are plentiful at that time of year. Ixodes dammini, collected on Shelter Island which is nestled between the forks of eastern Long Island, were sent to the Rocky Mountain Laboratories for possible rickettsial isolations. There, Willy Burgdorfer discovered long, irregularly shaped spirochetes in the digestive systems of these ticks. These spirochetes were isolated in pure culture also at the Rocky Mountain Laboratories. Once cultured, the spirochete could be used for diagnostic tests.

Did these spirochetes cause Lyme disease? Patients recently infected with a microorganism have antibodies in their sera which react with the organism. Sera collected from Lyme disease patients on Shelter Island in 1979 were sent to the Rocky Mountain Laboratories. These sera, but not those from normal controls, reacted with the tick borne spirochete. European ECM patients also had these antibodies and Ixodes ricinus ticks from Switzerland possessed the spirochetes. Furthermore, when spirochete infected ticks were fed on albino rabbits a lesion similar to ECM developed after several weeks. From this point, investigations progressed rapidly. The spirochete was isolated from the blood, skin (ECM), and cerebrospinal fluid of several patients. Thus, the common etiologic agent of both ECM and Lyme disease had been found. Based on studies of its DNA, the Lyme disease spirochete was determined to be a new species belonging to the genus *Borrelia*; to honor its discoverer, it was named *Borrelia burgdorferi*.

The Natural History of Lyme Disease

Borrelia burgdorferi is a loosely coiled left-handed helix, that is, it coils with about seven turns in a counterclockwise direction. It averages 30 um in length and the diameter of the cell ranges from 0.18 to 0.25 um--a size which allows it to pass through many filters designed to retain bacteria. Structurally, the Lyme disease spirochete consists of a protoplasmic cylinder which includes the cytoplasm, cytoplasmic membrane and surrounding peptidoglycan layer, and of a multilayered outer envelope which surrounds the protoplasmic cylinder. Sandwiched between the outer envelope and the protoplasmic cylinder are the axial filaments which are analogous to bacterial flagella.

Borrelia burgdorferi is transmitted to humans by the bite of an infected tick. Several species of hard ticks harbor this spirochete. Thus, along the North Atlantic coastline the principal vector is *Ixodes dammini*. On the West Coast, *Ixodes pacificus* has been implicated as the vector for Lyme disease while *Ixodes ricinus* has long been recognized as the vector of ECM in Europe. Lyme disease has also been described in Australia where the tick vector is still unidentified.

Lyme disease is found throughout the world. Cases have been reported from Central Europe, Great Britain, Scandinavia, Australia and North America. The geographic distribution of this disease in the United States is increasing. Lyme disease occurs in various foci along the North Atlantic coast from Delaware to Massachusetts. Clusters of cases are found in the upper Midwest in Minnesota and Wisconsin, in Texas, and along the Pacific coast in California and Oregon. Scattered cases occur in many other states.

Nearly all *Ixodes dammini* collected on Shelter Island, New York, a highly endemic area, contain spirochetes in their gastrointestinal systems. West coast *Ixodes pacificus* show only a 3% rate of infection which correlates well with the much lower incidence of Lyme disease there. Other arthropods carry spirochetes and both mosquitoes and deer flies have been implicated in the transmission of Lyme disease.

Ticks and their mammalian hosts from Lyme disease endemic areas have been examined for the presence of *Borrelia burgdorferi*. Field mice, voles and deer in endemic areas are infected with *Borrelia burgdorferi* as are all three developmental stages of *Ixodes dammini*. Spirochetes can be identified in dissected tick organs or in animal tissues by dark field microscopy, or after growth in culture. They are found in such small numbers in their mammalian hosts that it may take weeks of culture for their presence to be revealed. These techniques have been employed to show spirochetes in eyes, kidneys, spleens, livers, testes and brains of apparently healthly mammalian hosts. Borrelia burgdorferi have been found in several species of passerine birds and the patterns of increased geographic distribution of Lyme disease suggest that the spirochete is being spread by migratory birds.

The relative importance of the various wild hosts to the transmission of Lyme disease to humans has been discussed extensively. Many different species may serve as hosts for the larval and nymphal stages, but numerically the white footed mouse, Peromyscus leucopus, is most important. In one endemic area, white-footed mice hosted 95% of Ixodes dammini larvae and 97% of the nymphs. Because of the leap-frogging life cycle of the tick on its mammalian host, particularly the white-footed mouse, it is possible that the larvae acquires its infection from a mouse which had been infected earlier in the summer by the nymphal stage. In the absence of tick infestation, spirochetal infection persists at least 14 months in white-footed mice kept in the laboratory. Thus, the white-footed mouse is most likely the reservoir for Borrelia burgdorferi in the wild.

Although larvae and nymphs are found primarily on mice, the adult stage prefers large mammalian hosts, particularly deer. The adult tick looking for its blood meal is found in brush about one meter above the ground where it can easily attach to large mammals. Deer are also frequently parasitized by immature Ixodes dammini and these animals have been shown to be infected with Borrelia burgdorferi. Reduction of Ixodes dammini populations through reduction of the numbers of rodents has proved to be impractical and one attempt to reduce the numbers of ticks through management of the deer population failed. Currently, the best advice for the prevention of Lyme disease in an endemic area involves protective clothing, careful surveillance and the use of tick repellants.

The Clinical Course of Lyme Disease

Anyone who lives in or visits a Lyme disease endemic area from the spring to the fall can get Lyme disease. Ten percent of the summer residents of an endemic beach community in New York had antibodies specific for Borrelia burgdorferi in their blood and therefore had been exposed to the spirochete. Lyme disease affects both sexes and all age groups, although disproportionate numbers of children with the disease have been found in New York. This may reflect either children's outdoor activity or that they are more likely than adults to get medical attention. Lyme disease patients are more likely to own farm animals or cats.

ECM is the clinical hallmark of Lyme disease. Most patients seek medical attention for this lesion which, in its usual bull's eye form, is unlike any other skin rash. The erythematous rash expands from the site of the tick bite which itself may form a pimple-like red, swollen spot. The rash has been known to develop anywhere between 2 and 32 days after the tick bite though the rash may go entirely unnoticed in some patients and may be absent in others. Many first seek medical attention for neurologic abnormalities or arthritis.

There are three stages of Lyme disease. The first is characterized by ECM and is frequently accompanied by profound fatigue, fever, chills, general malaise, sharp headaches and sometimes backache. This stage may start a few days to weeks after the tick bite. The second stage of Lyme disease involves cardiac and neurologic complications or migratory musculoskeletal pain. Only about 8% of ECM patients develop cardiac involvement which is usually brief, ranging from 3 days to 6 weeks. These patients may experience palpitations, dizziness or shortness of breath: a few may even require a temporary pacemaker to control the rhythm of the heartbeat. About 15% of patients develop marked neurological complications during the second stage of Lyme disease. Most common is a combination of meningitis, a severe burning pain, especially in the neck (radicular pain), and Bell's palsy--a paralysis of the VIIth cranial nerve that controls many facial muscles. During the third stage, a few Lyme disease patients develop an encephalitic syndrome of long duration suffering somnolence, memory losses, emotional lability or an inability to concentrate.

The third stage of Lyme disease is characterized by the arthritis originally recognized by the two women in Connecticut. Joint symptoms occur in about 60% of Lyme disease patients developing within months to two years after ECM. Early joint involvement (which may be considered part of the second stage) is characterized by pain, often without swelling, which migrates from one joint to another after only a few days. More debilitating arthritis, which may not begin until months after ECM, suddenly produces markedly swollen, inflamed joints. Those most commonly afflicted are the knees and then usually one at a time; this may lead to difficulty in walking. Elbows, shoulders, and other large joints are affected more frequently than are the small joints. Attacks generally last a few days to a few weeks and their number and severity decrease with time, but in some individuals arthritis may become chronic. The pathologic changes of Lyme arthritis are indistinguishable from those that occur in rheumatoid arthritis. However, Lyme arthritis can be distinguished clinically because it is asymmetrical, and does not cause morning stiffness or the development of subcutaneous nodules.

Although deer and mice which carry Borrelia burgdorferi appear to be unaffected by arthritis and laboratory animals are highly resistant to development of joint involvement, people are not the only victims of Lyme disease. Arthritis characterized by painful, swollen joints in the legs of both dogs and horses which live in or visit Lyme disease endemic areas has been associated with Borrelia burgdorferi infection. Thus, Lyme disease is also rapidly becoming a veterinary problem.

Treatment

It had been known for many years that European ECM could be treated with antibiotics. Borrelia burgdorferi are sensitive and early Lyme disease may be treated with either oral penicillin or tetracycline. Erythromycin is also effective. Antibiotics given during the primary stage of Lyme disease (ECM) decrease the likelihood of developing neurologic, cardiac or arthritic complications. Since the development of antibodies specific for Borrelia burgdorferi is also arrested, ECM cases treated early sometimes cannot be confirmed serologically and the diagnosis of Lyme disease rests solely on clinical judgment.

Even the later stages of Lyme disease usually respond to penicillin therapy although hospitalization and intravenous treatment may be required. That early antibiotics are effective and even long standing arthritis is improved by treatment, suggests that the later symptoms of Lyme disease result from persisting live spirochetes.

Pathogenesis

Significant progress towards understanding the pathophysiology of Lyme disease has been made in the 6 years since the discovery of Borrelia burgdorferi. Though demonstrated to be present in all affected organ systems, spirochete numbers are always small. Thus, Lyme disease must result from the biological effects of a small number of organisms amplified by factors derived from either the organism or the host or both. We have examined both possibilities.

One of the most toxic bacterial products is known as endotoxin or lipopolysaccharide (LPS). Although the existence of spirochetal LPS had been postulated for years, no one had successfully demonstrated LPS in spirochetes known to be human pathogens. To investigate the possibility that Borrelia burgdorferi contain LPS we chemically extracted large quantities of spirochetes to harvest LPS from the bacterial outer envelope. Two procedures led to the same conclusion--the Lyme disease spirochete does possess an LPS. It has potent biological activities some of which may be important in the pathogenesis of Lyme disease. When the LPS was injected into rabbits it produced a fever within a few hours. When injected into human or rabbit skin it produced a rash similar to ECM. When bacteria divide or when they die LPS is released into the surrounding area. However, LPS from the small numbers of spirochetes found in Lyme disease patients is unlikely to account for the wide distribution of symptoms.

Work in our laboratories has led us to put forth an hypothesis concerning the pathogenesis of Lyme disease: the biological effects of Borrelia burgdorferi or of spirochete products are amplified by an endogenous mediator and that this mediator is responsible for the pathogenesis of the disease. We propose that interleukin-1 (IL-1) is the host derived mediator of the inflammatory changes of Lyme disease.

IL-1 is a macrophage-derived immunoregulatory protein which also acts as the molecular orchestrator of nonspecific host defense mechanisms against a variety of environmental insults. It coordinates the body's reactions to bacterial infection and trauma by regulating production of fever, neutrophil release from the bone marrow, acute phase protein synthesis by the liver, blood concentrations of iron, zinc and copper, and fibroblast proliferation. Human macrophages produce large amounts of IL-1 in response to Borrelia burgdorferi.

Interleukin-1 is itself a powerful inflammatory agent. Our recent studies show that IL-1 can induce an acute inflammatory response in the skin. High doses of IL-1 produce an expanding red halo that is indistinguishable from ECM. For IL-1 to be the mediator of ECM there must be sufficient local production following a tick bite. We already know that very few spirochetes are required to stimulate IL-1 release and we have calculated that there are enough IL-1 producing cells at the site of tick attachment to account for the development of ECM.

Several lines of evidence suggest that IL-1 is responsible for arthritic changes in joints including those of Lyme arthritis. When IL-1 is put into culture with cells from the joint it causes these cells to produce at least two potent mediators of arthritic changes--an enzyme called collagenase which can degrade joint tissue and prostaglandin E2 which promotes pain. IL-1 has been found in synovial fluids from patients with several kinds of arthritis and we have confirmed this finding for Lyme disease patients.

Conclusions

Lyme disease is now the most frequently reported tick transmitted illness in the United States, if not the world. The rapid elucidation of the etiology, epidemiology and natural history of this disease has resulted from collaboration and cooperation among scientists whose expertise spans a variety of interests. That it has a bacterial origin suggests that other bacterial diseases remain to be discovered. That a bacterial infection can produce chronic arthritis which is morphologically indistinguishable from rheumatoid arthritis also suggests that other arthritides may be due to bacterial infection.

Acknowledgements

The many contribitions of my collaborators Gregory Beck and Jorge Benach are gratefully acknowledged as is the support of NIH Grant AR 36028 for our experimental studies.

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FORAGING AND DISTRIBUTIONS OF SUBTERRANEAN TERMITES

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INTRODUCTION

Subterranean termites nest in scattered chambers in the soil and forage below and sometimes above ground to reach food items, i.e., materials that contain cellulose. Their local as well as geographic distribution usually is governed by a complex interaction among climatic factors, soil, vegetation, and other organisms (reviewed by Lee and Wood 1971). The relationship between these factors and termite foraging ecology is discussed in the current review.

ABIOTIC FACTORS

Temperature and Moisture

The importance of temperature and humidity in determining the geographic distributions of termites has long been recognized (Kofoid 1934, Emerson 1955, Collins 1969, Mannesmann 1972). Most termites live in tropical or subtropical regions, although some extend into temperate areas. The worldwide distribution of the Formosan subterranean termite *Coptotermes formosanus* Shiraki generally is confined within 35° N and S of the equator and is strongly influenced by temperature (reviewed by Su and Tamashiro 1987). In the Sonoran Desert, *Heterotermes aureus* (Snyder) occurs at elevations below 1,220 m, where physical and behavioral adaptations apparently allow it to inhabit very hot and dry areas (Collins 1969, Collins et al. 1973). Its distribution appears to be limited by low rather than high temperatures (Haverty and Nutting 1976). On the other hand, *Reticulitermes tibialis* Banks, the ecological equivalent of *H. aureus*, is limited by low moisture and high temperatures, and generally is found at elevations above 1,140 m (Haverty and Nutting 1976).

A number of environmental factors influence daily and seasonal foraging activity of subterranean termites. The foraging behavior of *H. aureus* (Haverty et al. 1974) and *Gnathamitermes perplexus* (Banks) (La Fage et al. 1976) is primarily affected by temperature at the food-soil interface as well as by moisture. Haverty et al. (1974) observed high but erratic numbers of *H. aureus* during the summer, with the highest numbers during the late summer and early fall and the lowest numbers during the winter months, followed by increased activity during the spring. Similar seasonal foraging trends of this species also were observed by Jones et al. (1987).

During the course of their field studies, W. L. Nutting, M. I. Haverty, and J. P. La Fage (pers. comm.) postulated that Sonoran Desert termites locate aboveground food items by their temperature-moisture shadows. Since then, Ettershank et al. (1980) have demonstrated that *G. tubiformans*

(Buckley) and Amitermes wheeleri (Desneux) use temperature-moisture shadows to locate large food items on the soil surface in the Chihuahuan Desert. Jones et al. (1987) similarly showed that H. aureus foragers preferentially attacked bait sites surrounded by the greatest amounts of vegetative cover. They speculated that foragers may detect subsurface thermal variation between vegetated and nonvegetated sites, preferentially occupying the former. Such factors likely are much less important for subterranean species in less arid environments.

Soil Characteristics

Because subterranean termites live in intimate contact with the soil, it is not surprising that features of this substrate other than soil temperature and moisture also affect their foraging behavior. The proportion of sand, silt, and clay in the soil profile is particularly important because it influences not only the termites ability to construct galleries, but also the stability of these constructions (Lee and Wood 1971). These authors cite examples of how the distribution of certain subterranean termites is affected by soil type. Reticulitermes spp. (Kofoid 1934) and C. formosanus (Ikehara 1957) are more prevalent in sandy soils than in less porous clay soils.

BIOTIC FACTORS

Food Resources

In his review of the feeding habits of termites worldwide, Wood (1978) listed living vegetation, dead vegetation, dung, humus, fungi, and other incidental items among their diet. However, few termite species attack living vegetation (Harris 1962). In the Sonoran Desert, subterranean termites utilize dead wood to a very large extent. Although many tend to be general feeders, they show distinct feeding preferences among the available plants. Haverty and Nutting (1975a) suggested that several desert termite species, including H. aureus, G. perplexus, Paraneotermes simplicicornis (Banks), and three Amitermes spp., each maintained a fairly exclusive niche through a characteristic mode of attack on a preferential selection of host woods.

The relationship between wood biomass and termite numbers has been investigated by Haverty and Nutting (1975b). The abundance of several oligophagous termite species was correlated with the biomass of superficial dead wood when the wood was a preferred species. However, more general feeders such as G. perplexus showed no such relationship with dead wood biomass.

Dead wood is an abundant food source that is continuously produced in the desert ecosystem. It apparently is produced faster than it can be consumed by termites. Haverty and Nutting (1975b,c) found that termites consumed wood in amounts that approached its annual production, but considerably less than was available at the site. Such data lend support to Emerson's (1955) contention that competition for food resources is less important than that for colonizing and nesting sites.

La Fage et al. (1973) and Haverty et al. (1976) have emphasized the importance of selecting a suitable food substrate when studying termite foraging behavior, because termite feeding habits ultimately influence the reliability of a sampling technique. Two conventional methods for sampling subterranean termites include bait sampling and soil sampling. Sands (1972) has reviewed the problems associated with these methods. The nature and size of the bait, as well as the way it is presented, may affect the reliability of bait sampling, while the clumped nature of social insect populations inherently limits the reliability of soil sampling.

Intra- and Interspecific Interactions

Competition.--Lee and Wood's (1971) review of the literature pertaining to competition indicates that many of the data are of an inferential nature. For example, the over-dispersed nature of termite mounds has been inferred to result from competition (Wood and Lee 1971, Baroni-Urbani et al. 1978, Darlington 1982). However, more direct evidence is provided by data indicating that discrete boundaries between *Hodotermes mossambicus* (Hagen) colonies (Nel 1968) as well as those of *Heterotermes aureus* (Jones 1987) are maintained by intraspecific aggression. Furthermore, the latter species does not forage independently of another common subterranean termite, *G. perplexus*, and the two species appear to interact negatively (unpublished data). Levings and Adams (1984) also have found that *Nasutitermes* spp. defend their foraging areas from other colonies both intra- and interspecifically. In southeastern Florida, *C. formosanus* has been observed to take over foraging sites of *R. flavipes* Kollar (Su and Scheffrahn 1988a).

Territoriality.--Bouillon (1970) characterizes the area occupied by a subterranean termite colony as being divided into one or more nests and the trophic field or foraging territory centered around the nest(s). The extent of each territory varies with the species, stage of colony development, colony size, and availability of food and other resources. Foragers may have to travel long distances to reach the water table or aboveground water sources, suitable construction materials, or food (Bouillon 1970). Territorial expansion of *H. aureus* has been found to coincide with periods of high foraging intensity and favorable environmental conditions (Haverty et al. 1975, Jones et al. 1987). Baroni Urbani (1979) has reviewed other aspects of territoriality among termites, including defense mechanisms, the distribution of territories, and territory size.

Researchers have used a variety of techniques to investigate the territorial extent of subterranean termites. Haverty et al. (1975) were the first to use analyses of spatial and temporal patterns of termite attack on baits to estimate foraging territory size of a subterranean termite species. They monitored territorial expansion of *H. aureus* in a large bait grid and estimated that the average *H. aureus* colony encompassed an area of 12.5 m^2. Although these authors cautioned that this was a somewhat arbitrary procedure for determining territorial extent, similar criteria have been used to estimate that territory size of *Anacanthotermes ochraceus* (Burm.) averages 29.3 m^2 (Hosny and Said 1980), and *Microcerotermes* sp. averages 31.8 m^2 and *Microtermes* sp. averages 18.2 m^2 (Badawi et al. 1984). Recently, Jones (1987) has shown that analyses of spatial and temporal patterns of attack on baits are inappropriate for delineating foraging territories of *H. aureus*.

The validity of using this technique for other termite species also should be investigated.

The excavation of subterranean termite colonies is a very time-consuming and labor-intensive process. King and Spink (1969) used this procedure to determine that galleries of a C. formosanus colony in Louisiana extended throughout an area of ca. 5,650 m^2. Colony extent of other more conspicuous mound-building termites in the genus Coptotermes also has been investigated via nest excavation. In Australia, Ratcliffe and Greaves (1940) traced C. lacteus (Froggatt) galleries to wood that was up to 48 m from the mound and found that the gallery system covered an area of ca. 6,050 m^2. Greaves (1962) found that a colony of C. acinaciformis (Froggatt) encompassed an area of ca. 1,600 m^2, and individual galleries extended as far as 47.5 m from the mound. He also traced galleries of C. brunneus Gay that extended a maximum of 45.7 m from the mound. Considering this distance as the radius of a foraging territory, he estimated that the colony encompassed an area of 6,550 m^2. Galleries of a fungus-growing termite, Macrotermes michaelseni (Sjöstedt), radiated ca. 50 m from the nest and the foraging territory of this colony was estimated at ca. 8,000 m^2 (Darlington 1982).

Radioisotopes were used to trace the nesting system of C. formosanus (Li et al. 1976), Mastotermes darwiniensis Froggatt (Spragg and Fox 1974, Spragg and Paton 1980), and four Australian mound-building species (Holt and Easey 1985). However, many researchers prefer to use marking materials that are less biologically hazardous.

Lai (1977), Lai et al. (1983), and Su et al. (1983a,b) have suggested that a dye, Sudan Red 7B, may be useful for studying the foraging behavior of subterranean termites. This marker remains in the termite tissues for several weeks or more and can be measured quantitatively. In a field situation, Lai (1977) and Su and Scheffrahn (1988b) used this dye to estimate the territorial extent of several C. formosanus colonies, and Su et al. (1984) used it to determine that this species randomly selected bait sites. Foraging territories of C. formosanus in an urban environment ranged in extent from 162 to 3,571 m^2 (Su and Scheffrahn 1988b). The territorial extent of several H. aureus colonies has been determined to encompass several hundred to several thousand square meters based on the release and recapture of termites dyed with Sudan Red 7B (Jones 1987).

Agonistic responses among termites of the same species, but from different sites have been used as a basis for delineating territories. This technique has been used to identify territorial boundaries of Hodotermes mossambicus and Trinervitermes trinervoides (Sjöstedt) (Nel 1968), Nasutitermes spp. (Thorne 1982, Levings and Adams 1984, Roisin et al. 1987), Microcerotermes beesoni Snyder (Tyagi and Sen-Sarma 1983), Reticulitermes spp. (Clément 1986), and Heterotermes aureus (Jones 1987). Nel (1968) used his data also to estimate that Hodotermes mossambicus territories averaged 92.1 m^2. Jones (1987), however, found that territories of Heterotermes aureus were estimated to be somewhat larger when using agonistic responses rather than data obtained via the release and recapture of dyed termites. It was suggested that a lack of aggression among colonies of this species may not necessarily imply a current relationship, as they may constitute subgroups that have previously budded off from each other. These subgroups presumably are headed by neotenic reproductives. Roisin et al. (1987) also have reported that the absence of aggression should be interpreted with caution because this behavioral response may occur in physically distinct colonies.

Furthermore, aggressive responses vary among some species. For example, laboratory pairings of C. formosanus from widely separated locations in Lake Charles, Louisiana, resulted in coalesence of the distinct groups (unpublished data), and a similar phenomenon is evident for this species in Charleston, South Carolina (M. Chambers, pers. comm.). In southeastern Florida, Su and Scheffrahn (1988a) reported the fusion of two field colonies of this species. However, aggression has been noted between colonies of C. formosanus in Hawaii (Su and Scheffrahn 1988a). Neither R. flavipes (Kollar) nor R. virginicus (Banks) from different locations in southern Mississippi interact negatively when colonies of the same species are paired in the laboratory (unpublished data). In Charleston, pairings of R. flavipes from geographically distinct colonies also have failed to demonstrate conspecific aggression (M. Chambers, pers. comm.). However, these behavioral responses should be monitored on a seasonal basis, particularly since Clément (1986) has noted seasonal variation in aggression for Reticulitermes spp. in western Europe.

A number of other sophisticated techniques also have been used to identify colony-specific chemicals. Clément (1986) has studied enzymatic polymorphisms among colonies to determine their genetic relatedness. Soldier diterpene patterns have been used to identify members of the same colony (Roisin et al. 1987).

COLONY AND FORAGING PARTY SIZE

The cryptic nature of subterranean termites has hampered determinations of the number of individuals in their colonies. Haverty et al. (1975) used data obtained via analyses of spatial and temporal patterns of termite attack on baits as the basis for estimating that the average H. aureus colony contained ca. 23,000 individuals. Destructive sampling techniques have been used to estimate that colony size of R. flavipes in southern Mississippi averages ca. 245,000 individuals (Howard et al. 1982) and C. formosanus colonies may contain several hundred thousand termites (reviewed by Su and Tamashiro 1987). Isotope dilution analysis has revealed that colonies of M. darwiniensis contained from 700,000 to 7,000,000 individuals (Spragg and Paton 1980).

Estimates of colony size obtained by a mark-release-recapture method generally have proven to be larger than those obtained via other techniques. For example, the foraging population of H. aureus colonies was estimated to range from ca. 40,000 to 300,000 individuals based on the release and recapture of dyed termites (Jones 1987). Esenther (1980) estimated that an extensive complex of several colonies of R. flavipes in Janesville, Wisconsin, numbered into the tens of millions of foragers and two individual colonies contained several hundred thousand to several million foragers each. However, his estimates were associated with unacceptably high coefficients of variation, which ranged from 45% to 65%. Lai (1977) and Su et al. (1984) used a mark-release-recapture technique to estimate that the foraging populations of several colonies of C. formosanus in Honolulu, Hawaii, exceeded one million individuals. I calculated standard deviations from the raw data provided by Su et al. (1984) and found that coefficients of variation associated with each population estimate were less than 10%. Recently, Su and Scheffrahn (1988b) used a multiple mark-release regime to estimate that *C. formosanus* colonies in Broward County, Florida, contained from 1.4 to 6.8 x 10^6 foragers.

Baroni-Urbani et al. (1978) have reviewed many of the methods for estimating colony size of social insects. They discuss a number of drawbacks associated with the mark-release-recapture technique, but conclude that it may represent the only practical approach for estimating population size of some species. Among the assumptions of this technique are that marked individuals become completely mixed in the population before they are sampled, the mark does not affect the behavior of the individuals, the mark lasts as long as the investigation, and the population under study is closed both geographically and demographically (Southwood 1978). Ayre (1962) has discussed problems with using this technique to estimate ant populations. He notes that, while it may be useful for estimating the total foraging population, total colony size cannot be determined if all individuals do not have the opportunity to be sampled because they never leave the nest. Physiological or morphological characteristics may determine the duties performed by a particular individual.

CONCLUSIONS

The above mentioned studies provide basic information on factors influencing the foraging and distribution of many species of subterranean termites. Many of these approaches can be applied to other termite species as well. Although subterranean termites are more difficult to study than those that nest or forage above ground, they should not be neglected. In natural ecosystems, subterranean termites play a complex role in the nutrient cycle. They are ubiquitous in tropical and subtropical regions as well as in many temperate areas.

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ACTIVITY AND DISTRIBUTION OF COCKROACHES WITH IMPLICATIONS TO DEVELOPING CONTROL STRATEGIES[1]

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Cockroaches are widely recognized as the most common insects encountered by man in the domestic and peridomestic environment (Rambo 1987). Their close association with humans, coupled with a propensity to feed on virtually anything produced, stored, consumed, discarded, or excreted by mankind, poses a threat to our health and well being, and clearly warrants every effort to manage cockroach populations safely (Brenner et al. 1987). Heightened sensitivity of the public to insecticides dictates that control strategies minimize use of toxicants. This may be achieved by recognizing and nullifying suitable habitats, or by careful placement of materials where the probability of encounter by the cockroach is high.

This paper will summarize ecological and behavioral research conducted in Florida during the past 3 years where the objectives have been to assess population dynamics of smokybrown cockroaches (*Periplaneta fuliginosa* [Serville]), Florida woods cockroaches (*Eurycotis floridana* Walker) and Asian cockroaches (*Blattella asahinai* Mizukubo). The text will focus on demonstrating how a greater understanding of the factors which govern the microdistribution, activity, and survival of cockroaches aid in predicting spatial distribution and rate of population expansion, which facilitate development of sound strategies for suppressing pest species. Although domestic species will not be discussed, the principles apply to these, and to vertebrate pests as well.

This research was undertaken with the assumptions that 1) cockroach behavior is predictable and is based on probabilities of survival, where critical factors are availability of water, harborage, and food; and 2) spatial distributions over time identify principal habitats where environmental characteristics define optimum conditions. Protocols include intensive systematic sampling (baited traps) of all ecological habitats (i.e., saturation trapping) over a period of 12 days to 4 weeks to assess focality, mark-release-recapture of both adults and nymphs to assess mobility and population levels, and computer-assisted analyses of spatial distributions relative to ecological profiles (Brenner 1988, Brenner et al. 1988).

Spatial Distribution of Peridomestic Cockroaches

Studies were conducted in late summer and early fall at 3 sites chosen for ecological diversity (Brenner 1988). Cypress landscaping mulch was used extensively at sites A and C, whereas deciduous leaf mulch and pine straw were used at site B. Trees at site A included roughly equal numbers of palms and young to mature hardwoods; trees at site B were dominated by young oaks and sweetgum, pines, and 2 palms; trees at site C were almost exclusively

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[1] Mention of a proprietary name does not imply endorsement by the U. S. Department of Agriculture.

mature oaks. Distributions reflected the ecological diversity. Spatial analyses of cumulative catches for 1030 trap-days (103 to 130 traps/site) revealed 86% and 75% of all cockroaches at sites A and C, respectively, were centered on trees -- specifically hardwoods with treeholes (Fig. 1) and palms. At site B, populations primarily were terrestrial (67%) and centered on thick plantings of cannas and areas of leaf mulch; arboreal populations once again centered on palm trees and treeholes in hardwoods.

Species composition was related to the dominant habitat at each site. Populations in palm trees were comprised of smokybrown cockroaches almost exclusively. This species also predominated in treeholes, but shared this space with Florida woods cockroaches. In terrestrial habitats, woodpiles contained both species, but the majority were Florida woods cockroaches; thick plantings and leaf mulch were occupied primarily by Florida woods cockroaches. Consequently, smokybrown cockroaches predominated at sites A and C where dominant habitats were arboreal, but this species was outnumbered by Florida woods cockroaches at site B where the majority of habitats were terrestrial.

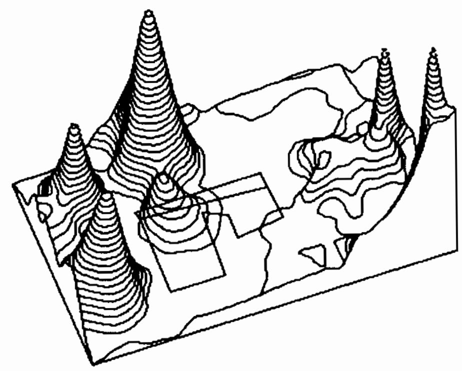

Fig. 1. Three-dimensional distribution of peridomestic cockroaches at site C. Contours are in intervals of 1 and represent cumulative catches during 10 days.

Overwintering Survivorship

Studies were also undertaken at site A to determine whether these patterns of distribution changed following winter, and to assess the effect of winter weather on survivorship (Brenner & Pierce, manusc. in prep.). Rainfall and maximum daily temperatures during the sampling periods (fall and spring) were not significantly different, and mean minimum daily temperatures were only slightly lower in the spring (21.5°C and 19.1°), suggesting that differences in population dynamics truly reflected the impact of winter. Nymphal proportions of smokybrown cockroaches were not significantly different between seasons (0.522 and 0.544 for fall and spring, respectively), suggesting that the observed population reduction of 65% affected nymphs and adults equally; spring populations of Florida woods cockroaches were 56% lower than fall populations.

There were some significant changes in distribution following winter as measured by percentages of daily catch by habitat. Although spring nymphal populations of smokybrown cockroaches remained well-established in the canopies of palms, adults were rarely captured there. Instead, their distribution was centered on the few trees with treeholes (Fig. 2). In contrast, a significantly smaller proportion of the nymphal population was captured in treeholes. This seasonal shift from nymphs to adults may be the result of maturation during winter of those present as nymphs in treeholes in the fall. Alternatively, there may be little growth of nymphs during winter; instead, a high proportion of adults sequestered in treeholes may survive. In either case, this habitat clearly represents a protective environment from which populations can expand the following spring. Other significant changes included decimation of both nymphal and adult populations associated with large potted plants and mulches near the base of the home, and reduction of adult smokybrown cockroaches in woodpiles.

The importance of arboreal habitats, and the partitioning of species according to ecological profiles are supported by observations of other researchers. Focalized distributions have been reported for smokybrown cockroaches (Fleet et al. 1978, Appel & Rust 1985); American cockroaches, *P. americana* (L.); (Cornwell 1968, Jackson & Maier 1955); and oriental cockroaches, *Blatta orientalis* L. (Beatson & Dripps 1972, Thoms & Robinson 1987). Some data even suggest an association with trees (Appel & Rust 1985, Beatson & Dripps 1972, Hagenbuch et al. 1988). Suitability of mulches, woodpiles, and treeholes likely is governed for each species by such factors as dimensions of interstitial space acceptable for harborage (Mizuno & Tsuji 1974), permeability of cuticle (e.g., rate of water loss and need for liquified water; Appel et al. 1983), and degree of air movement (rate of desiccation; Ramsey 1935).

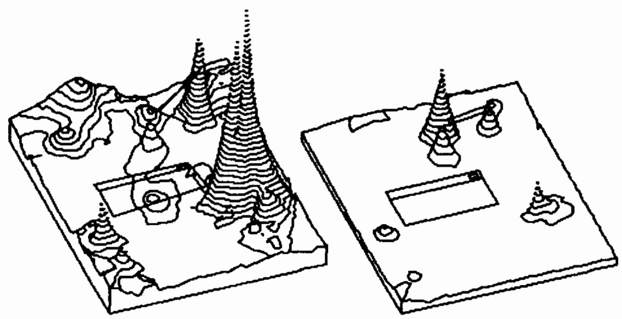

Fig. 2. Seasonal change in distribution of adult peridomestic cockroach populations. Contours on left reflect distribution in palm trees during the fall season; contours on right indicate a significant shift the following spring to hardwood trees with treeholes. Contours are in intervals of 1 and represent cumulative catches during 10 days of sampling.

In the peridomestic environment, treeholes can be considered the ecological equivalent of caves (Schal et al. 1984), and likely provide an optimum stable microclimate characterized by little air movement, abundant moisture and microbial food sources, warmth in winter, darkness, and protection from predators. Here, the probability of survival is high, whereas conditions in woodpiles and mulches likely are more variable and diminish long-term probabilities of survival for all but the hardiest species.

Mobility Patterns and Factors Governing Activity

Despite ecological diversity among research sites, patterns of mobility were uniform; time between recaptures averaged 3 trap-days, but mean net distance traveled between recaptures, computed by stage and sex for each species, ranged from 0.01-5.73 m; most were below 2 m, both mode and median distances were zero, and in most cases, adults were most mobile (Brenner 1988). Similar trends have been reported for smokybrown cockroaches in Texas (Fleet et al. 1978, Appel & Rust 1985) American cockroaches in Arizona (Jackson & Maier 1955, 1961), and oriental cockroaches in Virginia (Thoms & Robinson 1987). These cockroaches either move very little during foraging or mate seeking, or the overwhelming tendency is to return to the same focus. Regardless, focality is maintained and distributions continue to be predictable.

Stepwise regression analysis was used to determine the effect of low temperature, high temperature, and rainfall on the activity of these cockroaches. The threshold for activity was observed to be near 10°C for a night-time low. The best single predictor of activity was the change in precipitation -- i.e., activity was greatest the day following rainfall, and it was related to the quantity and hour of rainfall. Considering all factors, so long as minimum temperatures remain above the threshold, activity is best correlated with the change in precipitation and the maximum daily temperature. However, when temperatures are relatively high, change in precipitation and minimum temperatures govern activity (Brenner 1988).

Problems with peridomestic cockroaches are most common in the fall season in the Gulf states, and a common perception of homeowners is that mobility of cockroaches increases as these pests "seek" the more salubrious climate of man's dwellings as winter approaches. Seasonality of cockroach mobility was examined in these studies at site A, comparing fall and spring patterns. In contrast to common perception, adult smokybrown cockroaches were significantly more mobile in the spring (means of 1.13 m and 4.53 m, $P = 0.02$, df = 1, 107). The trend was similar for adult Florida woods cockroaches, but differences were not significant due to small sample sizes in spring. Differences in nymphal mobility between seasons were not significant for either species (Brenner & Pierce, manusc. in prep.).

Besides meterological parameters, crowding may result in increased mobility of cockroaches, as has been shown when additional American cockroaches, *P. americana* (L.), were superimposed on an existing population (Jackson & Maier 1955). Mobility of smokybrown cockroaches at a fourth site (site D) was compared to that at site A during the fall. Population densities (no./trap-day) at site D were twice that at site A, and mean mobility of adults was 3X higher ($P = 0.0001$) (Brenner & Pierce, manusc. in prep.).

Population Expansion to Secondary Foci

The cumulative results of these studies suggest that 1) principal habitats (at least for smokybrown cockroaches) are arboreal and are characterized by moisture, little air movement, warmth, and darkness; 2) mobility is minimal but may increase as principal habitats reach carrying capacity; and 3) adults are likely to be the dispersive stage. Consequently, population expansion will depend in part on 1) population levels relative to carrying capacity; 2) physical characteristics of expansion foci (suitability); and 3) proximity of expansion foci to principal foci. This pattern was evident at site D in the fall where nymphal smokybrown populations were high and limited to palm

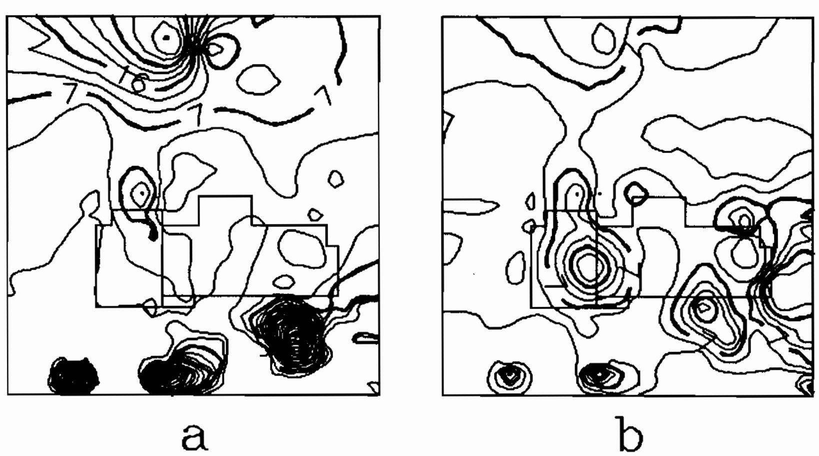

Fig. 3. Distribution of (a) nymphal peridomestic cockroaches corresponding to palm trees (front left) and a cracked block retaining wall surrounding a tree (front right), and (b) adult peridomestic cockroaches in the fall illustrating expansion of the population to loose flashing on the roofline, and to the deciduous leaf mulch and voids in the foundation block wall of the house. Contours are in intervals of 5 and represent cumulative catches during 10 days of sampling.

trees and a cracked block retaining wall surrounding an oak tree (Fig. 3a). Saturation trapping revealed limited adult populations at these locations, but other populations in deciduous mulch at the base of the home, in voids of the block wall foundation, and behind loose flashing (felt paper) where a flat roof adjoined the pitched roof (Fig. 3b). Absence of a substantial nymphal population in these locations implies that these serve primarily as expansion foci -- suitable habitats during the warm wet weather of late summer and early fall.

Examination of numerous homes, where nymphal peridomestic cockroaches were frequently sighted within the home, revealed attic infestations. Further inspection of attics disclosed populations largely confined to soffits and other areas characterized by low air movement (improper ventilation) and abundant moisture (primarily from damaged roofs, faulty flashing surrounding fireplaces, or improper drip-edge installation). In virtually all cases (ca. 30), cockroach populations in nearby identifiable habitats were high (Fig. 4). Observations at night, augmented by trapping, indicated that cockroaches enter attics through unscreened turbine, gable, scoop, or ridge vents, water-warped or damaged soffits, and loose roof boards (unpublished observations). The hypotheses resulting from the ecological studies conducted at sites A-D would predict the utilization of these attics as ecological equivalents of treeholes. Current research is focusing on modifying the attic environment to preclude entrance or to reduce survival of cockroaches.

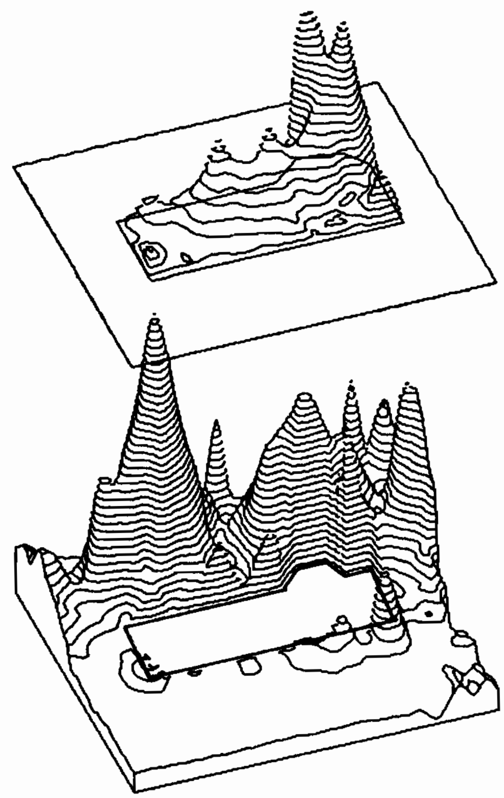

Fig. 4. *Two-stage presentation of peridomestic cockroach populations in trees and woodpiles surround a home (lower plot) and expansion to attic (upper plot). Contours are in intervals of 1 and represent cumulative catches during 10 days of sampling.*

Implications to Control Strategies

Predictability in spatial distribution, activity, and mobility of peridomestic cockroaches is conducive to a strategy based on the "CIA" concept of insect suppression, where control efforts are directed toward "Concentrated", "Immobile", and "Accessible" life stages (Horsfall 1985). Principal and expansion foci are visually recognizable and accessible, and a large proportion of the population can be intercepted before reaching expansion foci within the domestic environment. Use of baited traps or toxic baits placed on trees, in woodpiles, soffits of attics, near cracked block, and in areas of loose mulch (especially immediately following cool weather or an afternoon rain) would effect control with a minimum of toxicant applied to the environment. Such strategies have provided exceptional control for periods exceeding 6 months (Brenner & Pierce, manusc. in prep.).

Distribution and Mobility of Asian Cockroaches

Similar ecological studies on Asian cockroaches have revealed dramatically different behavioral traits which will limit the effectiveness of traditional control strategies for urban pests (Brenner et al. 1988). Spatial distribution studies correlated to environmental characteristics indicated that leaf litter, shaded areas of ground cover, or vigorous lawns are suitable habitats for this species. In heavily wooded areas, population estimates exceed 100,000 cockroaches per acre.

From a standpoint of CIA control strategies, the most damaging behavioral trait is flight ability and attraction to light-colored or brightly lit walls beginning at sunset. Adults gain entrance to the home by flying through open doors and windows, by passive transport via potted plants and lawn furniture, or by crawling around loose-fitting doors and window screens. Once inside, they are attracted to the brightest rooms where they perch on the brightest walls -- usually in close contact with humans occupying these rooms. Consequently, this pest is highly visible and repugnant to the residents; the tolerance threshold for this pest approaches zero. Thus, control efforts must virtually eliminate the possibility of Asian cockroaches getting to the home.

Mobility patterns were studied on 10 acres of heavily infested property. In a 48 hr period, marked adults flew as far as 36 m and marked nymphs moved as far as 12 m; directionality was biased toward the lights of the home. Based on these data, a regression equation predicted that treatment would need to be extended at least 18 m from a home in order to reduce the probability of Asian cockroaches reaching the home to near zero. Unfortunately, the "outlier" at 36 m becomes significant; although it truly represents a small proportion of the total population, this may translate to tens or hundreds of adults that will reach the home. Consequently, the predicted treatment zone of 18 meters likely is underestimated.

Suppression and Reinfestation of Asian Cockroaches

Control of Asian cockroaches was studied near an apartment complex west of Tampa to assess the impact of treating heavily infested woods (>100,000 per acre) with a granular mole cricket bait (Southern Mill Creek, Tampa, Flor.) for a distance of 30 m from the affected buildings (manuscript in prep.). Pretreatment counts at porch lights ranged from 50-207 per light, and residents reported nightly invasions of 10-55 cockroaches per apartment. Although an overnight reduction (sticky traps) of 85% was noted, flight to lights was reduced by only 55%. During the next several days, suppression reached 97%; this, and installing yellow light bulbs in porch lights, achieved reasonable levels of control, but failed to eliminate cockroaches entirely at the apartment buildings.

Posttreatment trapping was conducted to assess reinfestation potential. Even after only 10 days, it was apparent that adult populations were becoming re-established in areas under bright security lights between buildings and beneath street lights; by 2 mo. posttreatment, this pattern was pronounced (Fig. 5). Routine trapping over a period of 21 months provided evidence that reinfestation can be minimized if applications are timed carefully. Observations on population dynamics have revealed a seasonal shift in age structure, such that nymphs constitute over 95% of the population during June and July. Decimation of this age group at this time should further reduce reinfestation potential. Because these wingless stages are relatively concentrated in leaf

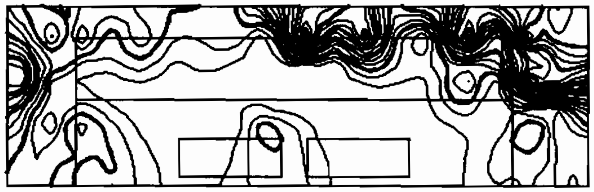

Fig. 5. Distribution of Asian cockroaches 2 months after treating 0.4 hectares, shown as the larger rectangle with a horizontal line that separates the grassy area (lower half) and wooded area (upper half). Reinfestation by adults corresponded to the security lights located between apartment buildings (2 smaller rectangles at lower center) and at lower left and lower right areas of the treated zone.

litter, the "concentration" and "immobility" components of the CIA strategy are realized.

However one unresolved issue remains --- target populations are legally inaccessible. In reference to the problem at the apartment complex, adult cockroaches entering the apartments were arising from 22 acres of undeveloped woods not owned by apartment management. Our research group obtained permission to treat the property as a research exercise, but agreed to assume all liability. Current laws prohibit pest control operators from treating areas not owned by their clients. Yet, inability to do so virtually guarantees constant nightly invasion and repeated rapid reinfestation. Consequently, the arrival of the Asian cockroach in this country necessitates an unprecedented regional control strategy similar to those under the direction of mosquito abatement districts.

Acknowledgement

Contour maps and three-dimensional illustrations were prepared using the "Surfer" mapping programs (Version 3.0, Golden Graphics, Golden, Colorado).

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A REVIEW OF PYRETHROID INSECTICIDES

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Introduction. Although the pyrethroids are seemingly numerous and bewilderingly complex in their names and structure, I hope during this presentation to highlight their main features, so that the choices which have to be made when using such materials to control insect pests in and around households, can be considered as a relatively rational process.

It is appropriate at this stage to give a brief outline of the history of the development of this group of insecticides because in this way the concepts and the materials which were subsequently derived, can be presented in reasonable sequence. This makes it easier to follow and remember the names.

It starts of course with Pyrethrum which has been known as an insecticide for a very long time, it has been said to have been used in China in the first century AD. Harvesting of the flower heads of the plant Chrysanthemum cinerariaefolium which were then dried and ground to produce an insecticidal powder became established in the Dalmatia area of what is now Yugoslavia during the second half of the 19th century. Seed was taken to Japan where it was grown widely from 1886 to the middle of this century. The present main growing area is East Africa where it was introduced in the early 1920s, but supplies are also available from Ecuador and Papua New Guinea, as well as other places. The commercial product is an extract, usually containing 25% pyrethrins, although more concentrated and refined extracts are available, as also are dried flowers and powder.

The active principal of this natural extract is a mixture of six active compounds which are known collectively as pyrethrins. They are formed by the esterification of the trans isomeric form of two acids, Chrysanthemic and Pyrethric, with each of three cyclopentenolone alcohols, Pyrethrolone, Cinerolone and Jasmolone to give Pyrethrin I & II; Cinerin I & II; Jasmolin I & II.

Pyrethrins show a wide spectrum of insecticidal activity with a rapid knockdown (KD) action; have low toxicity to mammals and are degraded in the presence of light. Sometimes this lack of stability in light is a disadvantage. Other inadequacies are that at low doses insect recovery can occur unless a synergist is present; they may be toxic to cold-blooded animals and supply can be variable dependant upon the harvest.

It is this last point, together with the shortage during the war period of the 1940s and thereafter, as well as the vision of Dr. Charles Potter at Rothamsted Experimental Station in U.K. who believed that active derivatives could be made, which stimulated various groups to examine synthetic routes to molecules of this type and the discovery of the pyrethroid group of insecticides. For convenience, the synthetic pyrethroids available commercially at present may be placed into the five groups indicated in the text below which are mainly but not exclusively, also in chronological order of discovery.

Esters of Chrysanthemic Acid. A significant improvement in the synthesis of chrysanthemic acid (Campbell & Harper 1945) led to a compound (Schecter et al. 1949) in which the side chain of the cyclopentenolone alcohol of the most active of the natural esters (Pyrethrin I) was substituted by an allyl grouping and hence named allethrin.

During the 1950s and early 1960s, work continued on the substitution of other alcohol structures and today we have available the compounds listed in Table 1.

Table 1. ESTERS OF CHRYSANTHEMIC ACID

Alcohol	Compound names
Allethrolone	allethrin series
Tetra,Phth	tetramethrin series - neopynamin
5B,3Fm	resmethrin series
3-Phenoxybenzyl	phenothrin series
α-Cyano,3Pb	cyphenothrin series
5Prop,2Fm	prothrin - furamethrin
2Me,5Prop,3Fm	proparthrin - kikuthrin
3,4,Me	dimethrin
2Me,4Ox,3Prop,Cyclopent	prallethrin - s 4068
4Me,Hept	vapothrin - s 2852 - empenthrin

Key to alcohols:
Allethrolone = 2-allyl-3-methyl-cyclopent-2-ene-4-ol-1-one
Tetra,Phth = 3,4,5,6-tetrahydrophthalimidomethanol.
5B,3Fm = 5-benzyl-3-furylmethanol.
3-Phenoxybenzyl = 3-phenoxybenzyl alcohol.
α-Cyano,3Pb = α-cyano-3-phenoxybenzyl alcohol.
5Prop,2Fm = 5-(prop-2-ynyl)-3-furylmethanol.
2Me,5Prop,3Fm = 2-methyl-5-(prop-2-ynyl)-3-furylmethanol.
3,4,Me = 3,4-dimethylbenzyl alcohol.
2Me,4Ox,3Prop,Cyclopent = 2-methyl-4-oxo-3-(prop-2-ynyl) cyclopent-2-en-1-ol.
4Me,Hept = 4-methylhept-4-en-1-yn-3-ol.

The earlier compounds were generally seen as pyrethrum substitutes rather than materials with individual properties. All were photolabile (a characteristic of both the chrysanthemic acid component and the alcohol) and their uses were confined to situations where this was not a significant disadvantage. e.g. domestic/industrial, outdoor (non-residual) and grain protection or glasshouse use. Some were pre-eminent at knockdown whilst others could most economically be used as killing agents.

Compounds which were developed as esters of 3-phenoxybenzyl alcohol and its α-cyano derivative, showed a significant improvement in photostability. When this characteristic was further enhanced by stabilisation of the acid, the opportunity was presented to consider pyrethroids as all-round insecticides suitable for use in nearly every situation.

Esters of Cyclopropane Halovinyl Acids. By 1974 it had been shown that stabilisation could be achieved by the substitution of the furylmethanol by a benzoyl group and then by halogenation of the acid. It was also found that activity could be considerably enhanced by using α-cyano derivatives and this led to the production of a number of excellent insecticides within this group, as shown in Table 2.

Table 2. ESTERS OF CYCLOPROPANE HALOVINYL ACIDS

Acid Alcohol	Compound names, numbers
DICHLOR VINYL	
3-Phenoxybenzyl	permethrin
α-Cyano,3Pb	cypermethrin series
α-Cyano,4F	cyfluthrin - FCR 1272
α-Cyano,Pyrid	fenpyrithrin - DOWCO 417
Pentf,Benzyl	fenfluthrin - NAK 1654
DIBROMO VINYL	
3-Phenoxybenzyl	NRDC 157, NRDC 163
α-Cyano,3Pb	deltamethrin -NRDC 161- RU 22974
2CLVINYL,4CLPHEN	
α-Cyano,4F	flumethrin - BAYTICOL

Key to alcohols:
As in Table 1 and
α-Cyano,4F = α-cyano-4-fluoro-3-phenoxybenzyl alcohol.
α-Cyano,Pyrid = α-cyano-(6-phenoxypyridin-2-yl) methanol.
Pentf,Benzyl = 2,3,4,5,6-pentafluorobenzyl alcohol.

Key to acids:
DICHLOR VINYL = 3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate.
DIBROMO VINYL = 3-(2,2-dibromovinyl)-2,2-dimethylcyclopropanecarboxylate.
2CLVINYL,4CLPHEN = 3-[2-(4-chlorophenyl)-2-chlorovinyl]-2,2-dimethylcyclopropanecarboxylate.

Such compounds could now take the place of conventional insecticides in public health uses and most importantly in the agricultural area. The introduction of fluorine atoms has given some characteristics which may be exploited, such as volatility, but can also increase mammalian toxicity hazards. Further series of compounds are shown in the following Tables 3-5.

Table 3. ESTERS OF OTHER CYCLOPROPANE HALO ACIDS

Acid	Alcohol	Compound names, numbers
CL,TRIF	α-Cyano,3Pb	cyhalothrin series - PP 321
	Tetraf,4Me,Benzyl	tefluthrin - PP 993
	2Me,Biphenyl	bifenthrin - FMC 54800
DICL	α-Cyano,3Pb	cycloprothrin - GH 414
TETRABR	α-Cyano,3Pb	tralomethrin
DICL,DIBR	α-Cyano,3Pb	tralocythrin
HEXAF	α-Cyano,3Pb	RU 38702

Key to alcohols: As in Tables 1&2 and
Tetraf,4Me,Benzyl = 2,3,5,6-tetrafluoro-4-methylbenzyl alc.
2Me,Biphenyl = 2-methyl-3-phenylbenzyl alcohol.
Key to acids:
CL,TRIF = 3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-
2,2-dimethylcyclopropanecarboxylate.
DICL = 2,2-dichloro-1-(4-ethoxyphenyl)-cyclopropane carboxylate.
TETRABR = 3-(1,2,2,2-tetrabromoethyl)-
2,2-dimethylcyclopropanecarboxylate.
DICL,DIBR = 3-(1,2-dibromo-2,2-dichlorethyl)-
2,2-dimethylcyclopropanecarboxylate.
HEXAF = 3-(3-[2,2,2-trifluoro-1-(trifluoromethyl)ethoxy]-
3-oxo-1-propenyl)-2,2-dimethylcyclopropanecarb/ate.

Tralomethrin and tralocythrin are of particular interest as "prodrugs" of deltamethrin and cypermethrin respectively, although they also possess activity in their own right (Ruzo et al. 1981).

Table 4. ESTERS OF OTHER RELATED HALO ACIDS

Acid / Alcohol	Compound names, numbers
CL,4F BUTYRIC	
α-Cyano,3Pb	fluvalinate - ZR 3210
4CL BUTYRIC	
α-Cyano,3Pb	fenvalerate - SUMICIDIN
4F,ME BUTYRIC	
α-Cyano,3Pb	flucythrinate - AC 222,705

Key to alcohols: As in Table 1.
Key to acids :
CL,4F BUTYRIC = 2-(2-chloro-4-trifluoromethylanilino)-3-methylbutyrate.
4CL BUTYRIC = 2-(4-chlorophenyl)-3-methylbutyrate.
4F,ME BUTYRIC = 2-[4-(difluoromethoxy)phenyl]-3-methyl butyrate.

Esters of Other Cyclopropane Acids and Other Compounds. Table 5 shows some of the other compounds which have reached the commercial stage out of the many which have been evaluated during the above developments.

Table 5. ESTERS OF OTHER CYCLOPROPANE ACIDS

Acid / Alcohol	Compound names, numbers
TETRAME	
Allethrolone	terallethrin - M 108
α-Cyano,3Pb	fenpropathrin - S 3206
2,OXOTHIO	
5B,3Fm	kadethrin - RU 15525
INDENE	
α-Cyano,3Pb	cypothrin - AC 206,797

OTHER COMPOUND

2-(4-ethoxyphenyl)-2-ethofenprox - MTI 500
methylpropyl 3-phenoxybenzyl ether.

Key to alcohols: As in Table 1.
Key to acids:
TETRAM = 2,2,3,3-tetramethylcyclopropanecarboxylate.
2,OXOTHIO = 2,2-dimethyl-3-(2,3,4,5-tetrahydro-2-oxothiophen-3-ylidenemethyl)cyclopropanecarboxylate.
INDENE = 3,3-dimethylspiro(cyclopropane-1,1-indene)-2-c/ate.

Hence in simple terms, the making of pyrethroids can be considered as the pairing of any of a range of acids and alcohols available.

The resultant compounds may be selected on cost effectiveness, depending upon the target pest, the method of application,the product, and the manufacturer.

Importance of Isomers. The activity of pyrethroids is very much governed by their shape which is a function of the isomeric form which is itself dependent upon the number and arrangement of saturated carbon atoms (chirality). Because of the geometry, a carbon atom with four different chemical groups attached can exist in two forms that are mirror images, known as enantiomers. Such compounds have the same physical properties (e.g.solubility, m.p.) and cannot be separated except by using reagents that are themselves asymetric.

If a compound contains two or more asymetric carbon atoms, then each can exist in two or more forms independently, and the total number of possibilities is 2^n where n is the number of asymetric carbon atoms. In such cases where some of the asymetric carbon atoms are of the same configuration and others are different, the compounds are not mirror images and are said to be diastereomers. These have different physical properties which often enable them to be readily separated.

Where compounds possessing asymetric carbon atoms are made by routes that do not involve asymetric reagents, a racemic mixture in which each isomer is accompanied by an exactly equal amount of its enantiomer is obtained.

Examples

```
            1R-cis,S   1S-cis,S   }
                                  }---  racemic 'cis'
            1R-cis,R   1S-cis,R   }

1R-cis,S    }                     1R-cis,S  }
            }--- enantiomers                }--- diastereomers
1S-cis,R    }                     1R-cis,R  }
```

In the pyrethroid group of compounds both the acid and alcohol components may have isomeric forms. The two most important alcohols with this characteristic are allethrolone and α-cyano-3-phenoxybenzyl. See also Janes,(1987) and Khambay,(1987) for comments on other aspects of chirality in pyrethroids.

The allethrin series shown in Table 6 illustrates the various forms of this chemical which are available commercially. Each of these is associated with a particular process which is usually only available to a specific manufacturer and thus confers a commercial advantage. For example, the 1R,cis,trans form of chrysanthemic acid is available from Sumitomo ("forte") and the 1R,trans from Roussel Uclaf ("bio") who also can produce the S form of allethrolone. This differentiation in the market follows through to the tetramethrin, resmethrin and phenothrin series. Other forms are preferred by other manufacturers for compounds where they have exclusivity.

Table 6. CONFIGURATION OF COMPOUNDS IN THE ALLETHRIN SERIES

		ratio c:t		ratio R:S alc	
1RS, cis,trans RS	allethrin	25	75	50	50
1R, cis,trans RS	d-allethrin	20	80	50	50
1R, trans RS	bioallethrin	0	100	50	50
1R, trans RS	esbiothrin	0	100	25	75
1R, trans S	S-bioallethrin	0	100	0	100

The activities of the separate isomers of allethrin and resmethrin are shown in Table 7 and illustrate the importance of isomeric form and activity.

Table 7. ACTIVITIES OF SEPARATE ISOMERS TO HOUSEFLIES

	ALLETHRIN	RESMETHRIN	
ISOMER	M.d. T.a. τ/insect	M.d. T.a. τ/insect	ISOMER
1R-cis,S	0.27	0.0413	1R-cis
1R-cis,R	1.2		
1R-trans,S	0.149	0.0126	1R-trans
1R-trans,R	0.445		
1S-cis,S	0.52	4.02	1S-cis
1S-cis,R	3.5		
1S-trans,S	1.8	1.77	1S-trans
1S-trans,R	6.5		

In general, mixtures of isomers exhibit either additive or antagonistic activity. It is therefore preferable, other things being equal, to use the purest forms of isomers available. However cost is also an important element in such decisions.

There is no specific configuration which confers maximum activity throughout the pyrethroid group although there has been a change from the 1R-*trans* of natural pyrethrins and the early series(chrysanthemic acid) to favouring 1R-*cis* with the halo acids and the S alcohol in the α-cyano 3PB series.

Insecticidal Properties. Mode of action and symptomology. Pyrethroids are nerve poisons. It is now generally accepted that the primary site of action of both pyrethroids and DDT is the sodium channel complex of the nerve membranes. During nervous transmission, "gates" normally open to allow the efflux of sodium ions and then close rapidly. The presence of the pyrethroids and DDT inhibit the closing so that depolarisation of the membrane continues.

Symptoms observed in insects treated with pyrethroids include activation, tremors, vomiting, increased water loss (diuresis), leading to paralysis which becomes more complete, then death. With many insecticides, the sequence of symptoms leading to death is irreversible but with natural pyrethrins and some of the synthetics at the appropriate dose, recovery may occur, seemingly entirely. This property greatly influenced the earlier use, formulation and perception of the group. This recovery feature happens less with the more recent pyrethroids.

There are two classes of symptoms shown by insects and these are reflected also in the different effects obsrved on mammals (Gammon et al. 1981).

In Type I, the symptoms in cockroaches are activation, incoordination, prostration, and paralysis. These are usually a response to pyrethroids lacking the α-cyano moiety.

In Type II symptoms, cockroaches show incoordination, convulsions, and intense hyperactivity. These are associated with pyrethroids containing the α-cyano group.

A scheme showing the general pattern of actions of pyrethroids on insects is shown in Table 8. The actions in the lefthand column are most easily seen. With small doses or shortly after exposure only the earlier effects may be seen and no mortality occurs. At impracticably large doses sub-lethal effects may be telescoped to invisibility. Cockroaches for example, can be paralysed whilst standing almost normally.

Table 8. ACTIONS OF PYRETHROIDS ON INSECTS

activation			
	repellency / expellency		
	anti-feeding	→	inhibition of feeding
knockdown		→	paralysis
	reproductive inhibition		
mortality			

The distinctive property of natural pyrethrins against insects is rapid knockdown. This was mainly exploited in "fly sprays" but equally affects other flying or crawling insects such as cockroaches. Knockdown does not equate to paralysis, the loss of any power of movement but is the inability to move in a sufficiently co-ordinated manner to progress normally. Although recovery can occur, the effects of dessication, dust, predation by ants and birds generally result in the death of the insect. Nevertheless a good formulation should result in the death of the treated insects without the aid of an outside agency and the need to achieve this greatly influenced the evolution of the pyrethroid business.

Recovery is due to metabolism of the pyrethrins, principally by the oxidation of the acid side chain, before irreversible damage is done to the nervous system. This can be inhibited by methylenedioxyphenyl synergists such as piperonyl butoxide which block the mixed function oxidase (MFO) system. The intrinsically rapid metabolism is strongly influenced by temperature, and can be observed as negative temperature co-efficients (lower toxicity at higher temperatures) shown by pyrethroids (Gammon 1978a,b; Scott 1987). Other groups of insecticides, with the exception of the DDT group, show positive co-efficients.

Flushing-out. The ability of pyrethroids to activate insects is an important aspect of their mode of action. Increased activity greatly assists the pick-up of insecticide from a spray cloud or a surface and hence increases the chances of picking up a lethal dose. In cockroach and triatomine bug control the "flushing-out" ability of an insecticide is an important feature (Wickham & Chadwick 1975; Pinchin et al. 1980). Chadwick (1975) has also shown the sequence of deterrency, expellency, interference with host finding, bite inhibition, knockdown and kill which feature in the performance of mosquito coils and other vaporising devices, both indoors and outdoors (Birley et al. 1987).

Repellency. The repellent action of pyrethroids is generally quite low and avoidance of treated areas by insects usually takes some time. When observed, it is most likely a response to an increase in activity and the initiation of a positive phototropism due to insecticide picked up from the treated surface which with the more potent pyrethroids, often constitutes a lethal dose (Nunn 1984; Buescher et al. 1987). The overall effect is to clear the area by effecting evacuation or by "killing out" the population. Such responses are involved in the use of pyrethroid treated bednets in mosquito infested areas (Kurihara et al. 1985; Snow et al. 1987; Charlwood & Graves 1987).

Anti-feeding. Other sub-lethal actions of pyrethroids are not easily established because of their high lethal potency but Ishaaya et al. 1983, reported drastic reduction of larval growth and anti-feeding effects against *Tribolium castaneum*.

The use of Synergists. The ratio of the concentrations needed to achieve a set level of effect when either alone or with the synergist, is termed the factor of synergism. The gain in effect is usually small where knockdown is concerned and may even be negative because the addition of the synergist slows the penetration of the pyrethroid to the site of action. The factor of synergism for kill may be much larger, even 10-15 times. With the pyrethrins this was particularly rewarding since the cost of the synergist was much less than that of the pyrethrins and a much more economical formulation was possible. A minimum amount of synergist appears to be necessary but above that level the gain diminishes logarithmically as the synergist to pyrethrins ratio increases (Chadwick 1963). Many of the later pyrethroids are less labile metabolically and for the most part show lower factors of synergism. Also, with their greater lethal activity, the effect has been to make lower proportions of synergist more economical. It should be observed here that some resistant strains of insects have enhanced oxidative powers and the resistance may be "blocked" by the synergist (Glynne-Jones 1983; Cochran 1987) an extension of the process in susceptible insects.

Part separation of knockdown and kill among the various pyrethroids has meant that the performance of a formulation could be adjusted to choice by using different proportions of KD agent, Kill agent and synergist. This offered considerable economies in cost and flexibility in formulation so that a wide range of products could be developed of the types illustrated in Table 9.

Table 9. TYPES OF PRODUCT

Space spray	indoor	pressure packed aerosol ready-to-use spray
	outdoor	thermal/non thermal aerosol ulv
Residual		pressure packed aerosol emulsifiable wettable powder flowable microcapsulation powder/granules
Vapour devices		mosquito coil vaporising mat
Impregnation of	timber	solution - mostly with fungicide
	wool	emulsifiable solution
Admixture with	grain	emulsifiable
	water	emulsifiable

Resistance. The categories in which resistance mechanisms in insects generally fall are shown in the left-hand column of Table 10. From the information given in the second and third columns it can be seen that mechanisms which bring about resistance to pyrethroids in insects seem to fall into three of these categories.

Table 10. RESISTANCE MECHANISMS

Speed of penetration		pen	Musca
Biochemical	Oxidase	MFO	Musca, Blattella
	Esterase		Musca, Blattella, Periplaneta
	Specific	DDT-Dehydrochlorinase	Musca
Sensitivity of site of action		kdr-type	Musca, Blattella, Culex
Behavioural		No convincing evidence.	
Excretion/Storage		Seemingly not important though the fat content of stages may be relevant.	

Resistance due to a decrease in the speed of penetration, controlled by the gene _pen_, has been described for houseflies by Farnham (1973). It was not found in _Aedes aegypti_ (Brealey et al. 1984) or in resistant _Culex quinquefasciatus_ (Priester & Georghiou 1980).

The prime biochemical mechanism acting directly on the molecule to confer resistance to pyrethroids is an increase in oxidative metabolism, with contributions from other processes such as ester hydrolysis (Shono et al. 1979; Soderlund et al. 1983). Enhanced oxidation is mainly associated with the microsomal mixed function oxidase (MFO) system present in organisms and can to a large extent be overcome by the use of a synergist such as piperonyl butoxide.

Perhaps the most emphasised mechanism is the change in sensitivity of the site of action. This is governed by a gene termed _kdr_ in houseflies because of the slower knockdown response to DDT noted during residual tests. It was found by Busvine (1951) that such flies also were resistant to natural pyrethrins. Similar mechanisms exist in a wide range of other species but it must be borne in mind that these are analogous, rather than identical, so it may be preferable to use the term _kdr-type_ generically. Both DDT and pyrethroids are resisted by this mechanism. This topic has been extensively studied by Sawicki and his colleagues at Rothamsted who have shown that several forms and intensifiers of _kdr_ and _Super-kdr_ exist in an allelic series of genes (Sawicki et al. 1986; Farnham et al. 1987).

Recognition of the probability of the type of resistance mechanism present in a sample of insects may be obtained by attempting to: - block the specific metabolic resistance to DDT due to DDT-dehydrochlorinase, with FDMC (1,1-bis(4-chlorophenyl)-2,2,2-trifluoroethanol), inhibit the oxidative processes by using piperonyl butoxide, inhibit esterase metabolism by using DEF (S,S,S-tributyl phosphorotrithioate), and if resistance is still observed, then _kdr-type_ is most likely to be responsible, although a decrease in rate of penetration is also a possibility. More direct proof is best found through electrophysiological tests (Omer et al. 1980). With _kdr-type_ resistance the threshold to open the sodium channels is raised by two or three orders but the observed change in LD50 is considerably less; often 5-20 times.

It is not unusual to find combinations of these mechanisms and in such cases, the total effect can be seen as multiplicative rather than additive (DeVries & Georghiou 1981; Scott & Georghiou 1986).

Clear evidence of resistance to pyrethroids due to behavioural changes appears to be lacking.

Resistance due to increased excretion or storage does not seem to be important although fat content is relevant to differences in susceptibility between stages and sexes. Many larvae with a high fat content, need large doses for kill. However, it is not entirely clear if this is not also an additional function of greater tolerance at the site of action.

Incidence and Importance of Pyrethroid Resistance. Much of the work published on resistance in the past decade has covered the pyrethroids rather than other compounds. This has given the false impression that resistance to pyrethroids occurs in the majority of populations of the majority of species, so rendering the group obsolete.

Resistance to any insecticide develops most rapidly if high selection pressure is applied to the whole of a (sub)population which contains an appropriate gene/mechanism, under conditions where no subsequent immigration of non-treated individuals can provide a resistant-gene dilution factor. This does not generally apply to populations of flying insects under standard pest control operations but the situation could be different where area treatments are used for crawling insect control. In aquatic situations, although the availability of pyrethroids is quite short, frequent repetitive treatments could predispose towards the development of resistance.

This is shown by two of the now classic cases, in which pyrethroid resistance has developed in field situations where populations were cohesive and local; a) The use of residuals to control fly populations in animal houses and b) The use of ear tags to control biting flies on cattle.

It is important to recognise that the diversity of structures and the related activity among pyrethroids, combined with the variety of specific resistance mechanisms, can assume great importance when dealing with strategies to minimise or overcome pyrethroid resistance (Robinson & Zungoli 1985; Scott & Georghiou 1986; Farnham et al. 1987). The use of insecticides and methods of application which ensure a lethal dose reaching the target insect also lessens the chance of resistance developing.

Mammalian Toxicity and Environmental Effects. Not all pyrethroids have low toxicity to mammals but all currently available are safe in use providing due recognition is given to the appropriate method and regimen of application.

The following Table 11 shows a comparison of indices of acute oral toxicity to rats against usage rates for insect control, for some pyrethroids and other insecticides commonly used in urban pest control.This data is not to be taken as definitive in assessing the relative merits of the compounds since no account has been taken of other aspects of the toxicity and insecticidal profiles that may be relevant to a given situation or use.

Table 11. COMPARISON OF TOXICITY TO USAGE INDICES

	Acute oral LD50 rats	Use Conc. $g.l^{-1}$	Index a/b
Deltamethrin (K-Othrin)	135	0.15	900
Cypermethrin (Fendona)	79	0.2	395
Cyhalothrin (Karate)	56	0.2	280
Permethrin (Perigen)	4672	2.0	2336
Bioresmethrin	7070	2.5	2828
Bioallethrin	425	3.0	142
Tetramethrin	>5000	3.5	>1428
Pyrethrins	584	2.0	292
DDT	113	20.0	6
Propoxur	90	10.0	9
Chlorpyrifos	135	5.0	27
Bendiocarb	40	3.0	13

Generally the cis isomers are more toxic to mammals than the trans because ester cleavage occurs less readily with cis (James 1980).

Another aspect which contributes significantly to the selectivity of the pyrethroids is their ability to penetrate rapidly to the site of action in insects; whereas they tend to be metabolised or excreted by mammals before reaching the nervous system. If injected into mammals they can be extremely toxic.

The routes of metabolism of pyrethroids in various biological systems is well documented - see reviews by Casida et al. 1979; Soderlund et al. 1983; Leahey 1979; and studies by Hutson & Logan 1986; and Edwards et al. 1987. Degradation is primarily by ester cleavage and hydroxylation of; the gem-dimethyl group on the cyclopropane ring; of the side chain of chrysanthemic acid; and at several positions on the alcohol moiety, depending upon the compound.

Transport and Distribution in Soil and Water. Pyrethroids have a great propensity to become absorbed onto surfaces and various studies have shown that upon contact with many types of soil they are held in the first few centimetres and cannot readily be leached (Kaufman et al. 1981; Hill & Schaalje 1985). Therefore, the run-off water from treated areas does not transfer these materials into streams and rivers nor does water transfer them within soil. A further cosequence is that even when directly applied to a river or body of water, the sediment therein can readily absorb the active ingredient and quickly reduce the amount available to aquatic organisms (Barlow et al. 1977; Kerhoas et al. 1980; Muir et al. 1985).

The relatively high acute toxicity to fish shown in laboratory studies is very much ameliorated under field conditions (Muir et al. 1985) and studies by Mulla et al. (1978), showed no mortality to four species of fish present in ponds used for mosquito larvicide trials. Although no mortality of fish occurred when streams were sprayed during an aerial treatment some lowering in growth rates and population densities was noted but both had recovered within four months after treatment (Kingsbury & Kreutzweiser 1987).

It must also be borne in mind that pyrethroids are potent arthropodicides and effects on non-target organisms from this group are likely to result from aquatic contamination. If this is not extreme or extensive, then re-colonisation from untreated areas is probable because of the rapid removal of pyrethroids from water as noted above. During aerial spraying operations it is to be expected that some drift of aquatic organism will occur and in one trial with permethrin, recovery was apparent from 1 to 18 months post-spray (Kreutzweiser & Kingsbury 1987). In normal use the risk of environmental contamination is therefore very small (Smith & Stratton 1986) but where it does occur the consequences for aquatic invertebrates could be catastophic in the short term.

Conclusion. In conclusion, it is apparent that the existing pyrethroids are of considerable benefit when controlling pests in urban situations because of the many features outlined above which set them apart from other materials. During the period of their development we have learnt that to make the best use of any insecticide we must be prepared to adopt control management programmes which take into account the pest biology, the timing and method of application, the attributes of the insecticide and any ancilliary procedures, and the likely impact on non-target organisms. The variety of pyrethroids now available provides sufficient flexibility to enable their use as integral parts of every urban pest management system.

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CARPENTER ANTS

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Carpenter ants have been recognized as structural pests for years. However, the most recent information on the economics of carpenter ants indicated that this perception may be, at least in part, erroneous. Fowler (1986) cited literature indicating that carpenter ants were more of a nuisance pest that rarely caused structural damage as they prefer to nest in preexisting voids rather than excavating materials to enlarge their nest. However, most of the data pertained to carpenter ants in the Northeast. In the Pacific Northwest carpenter ants cause serious structural damage as well as qualifying as nuisance pests (Hansen and Akre 1985).

Fowler (1983) also stated that carpenter ant complaints were increasing yearly in the northeastern United States. He suggested these complaints were a function of swarming activity by the ants, with the greatest number of homeowner complaints occurring in the spring. There is no question that these flights cause great concern, and many complaints are received by university personnel and pest control operators at this time. However, it would appear that several other factors should also be considered when investigating the increase in number of complaints. Since the energy crisis of 1973 many homeowners began to use wood as a heat source. Thus, hundreds or even thousands of colonies of carpenter ants have been brought into towns and cities in firewood that is frequently stacked against the sides of houses and garages. This poor practice facilitates the rapid entry of ants into the house. These imported colonies have vastly increased the spring swarming flights in some areas so that it is nearly impossible to walk without stepping on carpenter ant queens. Also, inspections are being required by power companies after energy audits before the utility will pay for insulating houses, and more carpenter ants and other wood destroying insects (powderpost beetles) are being discovered during these inspections. There is also an increasing awareness of structural pests among home buyers and finance companies. Therefore, inspections are becoming mandatory before home loans are approved, and the known incidence of carpenter ant infestations is increasing. Lastly, many universities are adding extension and research personnel who specialize in structural pests, so urban dwellers now have professionals to receive their complaints about these insects.

How important are carpenter ants as structural or nuisance pests? In the state of Washington, a conservative estimate of 42,000 structures are treated annually for these ants (Hansen and Akre 1985). Therefore, at least several millions of dollars are expended for their control in the Pacific Northwest. Fowler (1986) presented data, extrapolated from several sources, that showed these ants cause millions of dollars of damage each year in the Northeast. Damage assessed included that to houses, to forest trees, to urban park and ornamental trees, and also included costs associated with control. Earlier reports by Graham (1918) in Minnesota showed that infestations in white cedar ranged from 15 to 70%, depending on locality. Similarly, Sanders (1964), in New Brunswick, found that 10% of the merchantable crop of spruce and balsam fir was lost to carpenter ants. The most obvious conclusion is that damage and economic loss are considerable, but no definitive data exist.

However, reports from Cooperative Extension personnel in three widely separated northern states indicate that ants, particularly carpenter ants, are a serious problem (Tables 1-4). In western Washington, an area of high rainfall with many houses in forested areas, carpenter ants and moisture ants (*Lasius, Acanthomyops*) frequently rank among the top three pest insects sent in for identification (Table 1). Although eastern Washington is very dry (10-22 inches rain annually) and much of it is not forested, ants are also becoming a more frequent problem as wood infested with ants is trucked into the area for heating (Table 2). This is especially true in the Pacific Northwest where many people buy their wood in log decks (logs 6-10 m long) which are unloaded into a lot adjacent to their house where it is sawed into firewood. Carpenter ants are also perceived as serious pests in Ohio and Minnesota (Tables 3, 4). We suggest that as more states record inquiries about pest insects, carpenter ants will rank among the top pests in all northern states, while termites and cockroaches will hold these top ranks in the South.

Table 1. Ranking of the three most frequent arthropods sent for identification to the Insect Diagnostic Laboratory, Western Washington Research and Extension Center, Washington State University, Puyallup, WA, 1978-1987. In 1984 power companies initiated energy audits of houses and requests for identifications of wood boring beetles increased dramatically. Also, articles in Seattle newspapers in 1984 resulted in more carpenter ant inquiries and specimens being sent to WSU at Pullman. Still, carpenter ants ranked 4th that year. In 1987, the aggressive house spider, *Tegenaria agrestis* (Walckenaer), a newly discovered venomous spider, was responsible for the high frequency of spider identifications. (A. L. Antonelli, Extension Specialist).

	78	79	80	81	82	83	84	85	86	87
Carpenter Ants	1	1	1	1	1	1	-	3	3	2
Moisture Ants	2	-	2	-	-	-	-	-	1	-
Other Ants	-	-	-	-	-	-	2	1	-	3
Wood-boring Beetles	-	-	-	2	2	3	1	2	2	-
Meal Moths	-	-	-	-	-	-	3	-	-	-
Termites	-	2	-	-	-	-	-	-	-	-
Carpet Beetles	3	-	-	-	3	-	-	-	-	-
Spiders	-	-	-	-	-	-	-	-	-	1
Collembola	-	3	-	-	-	-	-	-	-	-
Drugstore Beetles	-	-	3	3	-	-	-	-	-	-
Psocids	-	-	-	-	-	2	-	-	-	-

Table 2. Ranking of the three most common arthropods submitted for identification to the Insect Diagnostic Laboratory, Pullman, WA, 1986-1987. All ant identifications were combined for presentation below, but carpenter ants ranked 4th and 5th, 1986-1987. The ranking from this laboratory is somewhat deceptive in that most ants sent to Pullman for identification go directly to research personnel. Unfortunately, records from this source were not retained until 1987 and are not represented. (Dan Suomi, Extension Specialist).

	1986	1987
Ants	1	3
Pantry Beetles	2	2
Spiders	3	1

Table 3. Ranking of the top three household and structural pests by frequency of inquiries to Ohio State University Extension Personnel, January to December 1983 to 1985, May to October 1986, and April to October 1987. The procedure was changed in 1986 so that data for 1986 and 1987 was collected from a pilot survey of urban pest inquiries in 25 Ohio counties. This survey ranked the top 100 pests affecting the public. The 1983-1985 data were comprised of 3,555 total inquiries about insects. The 1986 data were based on 7,619 survey responses; 1987 totaled 31,856. (William F. Lyon, Extension Entomologist).

	1983	1984	1985	1986	1987
Carpenter Ants	1	2	2	3	1
Yellowjackets	-	1	1	2	-
Carpet Beetles	2	3	-	-	-
Fleas	3	-	3	-	-
Other Ants	-	-	-	1	3
Termites	-	-	-	-	2

Table 4. Ranking of the three most frequent queries about insects, 1983-1986, Minnesota Extension Service, Dial-U Insect and Plant Information Clinic. (Jeffry D. Hahn, Extension Educator).

	1983	1984	1985	1986
Carpenter Ants	1	1	1	1
Wasps (yellowjackets)	3	3	3	3
Cockroaches	-	2	3	3
Insect Galls	2	-	-	-
Other Ants	-	-	-	2
Total Contacts	6,142	6,421	9,223	7,863

Biology

The most damaging species of carpenter ants in the PNW are *Camponotus modoc* Wheeler and *C. vicinus* Mayr (Hansen and Akre 1985). The first is by far the most important structural pest in Washington State, and knowledge about certain aspects of its biology are critical to understanding why it is such a pest species. Most colonies are comprised of a parent or main colony containing the queen, workers, and brood, and a number of satellite colonies consisting of workers and brood. In many cases the main colony is located in a hollow live tree or in a dead log or stump. Satellites are usually located in other dead or live trees adjacent to the parent colony, and the total area occupied by the colony may encompass several hectares or more. Our estimates of the largest colonies collected in the last 7 years are in excess of 100,000 workers.

It is especially common in western Washington to build houses on forested lots with a minimum removal of trees. Unfortunately, nearly all forested lots contain one or more carpenter ant colonies, and the newly constructed house is frequently invaded by satellite colonies even before construction is completed. Thus, homeowners are usually not dealing with colonies arising slowly from the progeny of a single queen, but their houses suffer from the damage of 5,000 to 50,000 workers in satellite colonies that have moved into the structure. Since these houses and other man-made structures have optimal temperature and moisture conditions for the rearing of brood, they are ideal nesting sites.

In all cases trails are maintained between satellite colonies and the main colony in addition to trails to foraging sites. The trails are both chemical and physical and are very similar to trails produced by leafcutting ants. Trails that cross grassy areas are kept clean of all vegetation and debris by the ants and are often quite noticeable (Figs 50-53, Hansen and Akre 1985). Foraging by workers of *C. modoc* and *C. vicinus* on these trails is heaviest from dusk until dawn, although some traffic may occur during daylight hours. These trails make finding the main or parent colony easier, and this segment of the colony must be located and killed to achieve lasting control.

The biology of eastern species of carpenter ants has been studied by Pricer (1908) in Illinois, by Fowler (1982) in New Jersey, and by Sanders (1964, 1972) in New Brunswick and northwestern Ontario. Species included were *C. pennsylvanicus* (DeGeer), *C. herculeanus* (L.), and *C. noveboracensis* (Fitch). In eastern Canada colonies of these species also divide into main and satellite segments.

Control

In nearly all cases, as with all structural pests, the main reasons that these insects become a problem are because the structures were built incorrectly, there were improper uses and storage of wood around the structures, and/or potential pest colonies were not eliminated before construction began. Hansen and Akre (1985) showed that most infestations occurred in houses where conditions were optimal for invasion by ants. These conditions include: crawl spaces instead of basements, soil in contact with wood, vegetation in contact with the building, inadequate ventilation, and/or numerous openings for electrical lines, water lines, openings caused by breaks in the foundation walls, or other small openings left by shoddy construction or the use of inferior materials. Other factors contributing to infestations include the poor practice of stacking firewood against the walls of the structure, and the practice of landscaping yards with used railroad ties or other large timbers, These wood products, in constant contact with the soil, make ideal nesting sites for the ants and often harbor a main colony.

To reduce the possibility of carpenter ant infestations, any forested building site in a carpenter ant area should be inspected by a person knowledgeable about these ants and their nesting habits. Trees and other wood materials containing carpenter ants should be eliminated or treated with an insecticide before construction begins. It is essential that waste wood, including stumps, be removed from the site or burned. Currently it is a common practice in many areas to bury these materials, a practice which creates ideal nesting sites for carpenter ants and termites. Additionally, these colony sites are among the most difficult to find since they are completely underground.

Ideally, carpenter ant control includes proper construction procedures in regards to new structures, repair of faulty construction of existing dwellings, regular inspections for ants in areas with high risk of infestations, and locating the parent or main colony if an infestation exists. It is essential that the main colony be eliminated. Good control is effected by locating the ants in the house and treating the area with an insecticide, usually a dust formulation, by applying the the material in wall voids through cracks adjacent to electrical outlet boxes and through other existing breaks in the walls and ceilings. Otherwise dust or spray can be applied by inserting a small wand through 2mm holes drilled into the wall void in inconspicuous areas. Electrical lines, water pipes, and other convenient avenues that the ants use as trails to travel through the studding in walls must also be treated. Outside the structure all breaks where ants can enter the home are treated, and a perimeter spray is applied against the foundation wall, under the lower edge of sidings, and around window and door frames. If the house has a crawl space instead of a basement, the inside of the foundation and the sill plate should also be sprayed (Akre et al 1984).

In the PNW 22 chemical compounds in about 60 formulations and sold by 31 companies are registered for carpenter ant control. However, this includes some materials best classified as wood preservatives and methyl bromide used as a fumigant. Fumigation is ineffective and very costly (three fumigations in the Seattle area cost a total of $49,000). It is not recommended except under unusual conditions. More effective materials include boric acid or bendiocarb as dust formulations placed into wall voids, and cypermethrin, chlorpyrifos, encapsulated diazinon, or propoxur, as perimeter sprays. In addition, cyfluthrin, a long lasting pyrethroid insecticide that is very effective as a perimeter spray, will soon be registered for carpenter ant control. The use of synthetic pyrethroids reduces the number of perimeter sprays needed yearly in high infestation areas from the current 3-4 to a single application.

In addition to sprays, there are at least two commercial toxic bait materials for carpenter ants. However, neither of the bait materials are very attractive to these ants. The toxicant used in the bait is effective, but the ants do not readily feed upon it nor carry it back to the brood. However, we have develped a bait material that is readily fed upon by *Camponotus modoc* and *C. vicinus* , and several materials have been tested as toxicants. This bait has not been tested for attractiveness to the eastern *C. pennsylvanicus* . At least one toxic bait should be available commercially in the West in about 2 years.

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AN ECOLOGICAL PERSPECTIVE OF THE HOST-PARASITE RELATIONSHIP OF THE CAT FLEA

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The cat flea, *Ctenocephalides felis felis* (Bouché), is a cosmopolitan pest of medical and veterinary importance, especially in urban situations. Of the nine species belonging to the genus *Ctenocephalides*, only *C. canis* (Curtis) and two subspecies of *C. felis* have been widely collected from outside the Ethiopian Region (Table 1). *C. arabicus multispinosus* Smith and *C. paradoxuri* Wagner are known from limited collections on hyrax *Procavia* and *Paradoxurus* spp. from Israel and Sri Lanka, respectively. About half of the species of *Ctenocephalides* are monoxenous on hosts such as hyrax or squirrels *Xerus* whereas the remaining species are typically polyxenous on carnivores. *C. f. felis* has been widely collected on domestic cats and dogs, opossums, and mongooses from all zoogeographical regions. In addition, they have been collected on some 20 other species of mammals, including man. Clearly, the association of the cat flea with the domestic cat and dog is largely responsible for its current distribution.

In addition to domestic cats and dogs, other frequently-reported hosts of *C. f. felis* found in urban environments include various species of opossums, *Didelphus* spp., and mongooses, *Herpestes* spp. To a lesser extent carnivores such as bobcat, fox, civets and mustelids such as mink, ermine, and ferrets have also been reported as hosts. Hopkins (1980) reported that *C. felis* and *Nosopsyllus fasciatus* Bosc were the most common fleas on opossum in Portland, Oregon, attributing their presence to domestic cats and dogs and rats in urban areas. Surveys by Amin (1976) in Wisconsin failed to collect cat fleas from opossums even though four other species of fleas were found. Similarly, Haas (1966) reported widespread infestations of cat fleas on mongooses in Hawaii, whereas Pimental (1955) reported less than 5% of the mongooses in Puerto Rico infested. During the spring of 1987, the den of a California grey fox behind our laboratory was heavily infested with cat fleas for 4-8 weeks after the fox and her kits left, providing a potential source of fleas for stray cats living around the buildings. Cat fleas are occasionally encountered on various rodents in very low numbers in the western United States during plague surveys, especially those rodents collected from farms, dumps and refuse areas (Prince 1943). In Mobile, Alabama, Cole and Koepke (1946) found that cat fleas were associated with Norway rats in residential areas. The incidence of cat fleas on feral hosts appears to be closely associated with urbanization and the presence of domestic pets.

The specificity and diversity of the environment of a parasite-host system can be considered to consist of two environments, a first order (the host's body) and a second order (the host's habitat). This categorization (as reviewed by Janion 1979) provides a convenient framework to explore the ecology of the cat flea because of the adult flea's dependence on the host

Table 1. The geographical distribution and primary hosts of members of the genus *Ctenocephalides*.[a]

Species	Country or Geographical Area	Hosts
arabicus arabicus	Yemen	hyrax (*Procavia capensis*)
a. multispinosus	Israel	hyrax
canis	cosmopolitan	domestic dog, canids
chabaudi	Gabon	accidental host?
connatus	South Africa	squirrel (*Xerus* spp.) viverrids, rodents
crataepus	equatorial Africa	squirrel (*Xerus* spp.)
craterus	Kenya	hyrax
felis damarensis	East Africa	carnivores
f. felis	cosmopolitan	domestic cat and dog carnivores
f. orientis	India-Australia	carnivores
f. strongylus	East Africa	carnivores
paradoxuri	Sri Lanka	carnivores
rosmarus	Ethiopia	hyrax

[a] Compiled from Beaucournu and Bain (1982), Hopkins and Rothschild (1953), and Lewis (1972).

(1st order) and the immature stages dependence on the host's habitat (2nd order). These ordered environments may include biological or morphological adaptations that ensure contact with the host or survival away from the host in a nest or burrow. We know considerably more about the 2nd-order environmental interactions from our studies of flea development than we do about the 1st-order interactions.

Adult cat fleas are believed to remain on an individual host for their entire adult lifespan unless they are dislodged during grooming. The immature stages develop in sheltered microhabitats such as nests, burrows, or places where animals rest. Cat flea eggs fall from the host's pelage to substrates where hatching occurs within 2-3 days. Exposure to relative humidities below 43.5% RH severely inhibit hatching, with less than 31% RH completely preventing hatching. The three larval instars develop over a period of 6-36 days depending upon the temperature and relative humidity (Silverman et al. 1981). Even brief exposures to low relative humidities (33% RH) were lethal, especially at temperatures above 27°C. For example, a 16-hour exposure of larvae to 33% RH at 27°C resulted in 63% mortality (Silverman and Rust 1983). Mohr and Mohan (1959) reported that *C. felis* larvae caught in opossum burrows failed to develop whereas larvae caught in nearby fox dens developed into adults. They attributed the lack of development in opossum burrows to unfavorable temperature and humidity conditions. Similarly, Flux (1972) found that the increased incidence of cat fleas on the hare *Lepus capensis* in Kenya was directly related with higher elevation (1800 m) and cool and moist climatic conditions (18°C and 50-80% RH). This is just the opposite of conditions in the southwestern United States where cat fleas are primarily found along the coast and rarely found above 1800 m because of extremely low moisture conditions.

In the process of developing into the pupa and a pre-emerged adult within the cocoon, physiological changes in the larva occur that increase the likelihood of surviving adverse environmental conditions. Silverman and Rust (1983) showed that the pre-emerged adult flea in the cocoon was capable of withstanding exposures of 8°C for 10 days whereas less than 45% of the larvae or pupae survived similar exposures. About 38-45% of the pre-emerged adults or emerged adults survived 20-day exposures to 8°C, indicating cat fleas might be able to overwinter in protected host's burrows or nests. Silverman et al. (1983) showed that pre-emerged adults in cocoons were capable of withstanding exposures to very low relative humidities. About 65% of the pupae exposed to 2% RH developed and adults emerged from cocoons. As pointed out by Silverman and Rust (1985) the pre-emerged adult in the cocoon provides the adult cat with some degree of independence from 2nd-order environmental conditions and is an important adaptive strategy, allowing the flea to wait for suitable hosts to return to nesting or resting sites. This is especially important for flea species like the cat flea whose hosts may make very loose or temporary nests or forage over large distances.

Our knowledge of 1st-order environmental factors associated with the host's body is primarily limited to flea surveys conducted on trapped animals, studies of fleas confined to hosts, and experiences associated with cat flea rearing. Surveys of cats, rats, and mongooses show a definitive seasonality to cat fleas populations. Lyon (1915) found that the percentage of cats infested increased dramatically at the beginning of the summer (Table 2). A similar pattern was reported by Kristensen et al. (1978) in Denmark. Osbrink and Rust (1985) reported increasing numbers of fleas and higher percentages of cats infested with increasing spring temperatures and a second peak in the fall in southern California. It may be more than coincidence that the estrus cycle of cats begins in January and lasts until March, terminating in gestation about 65 days later and that a second estrus cycle begins in June-July in the United States (McDonald 1969). Haas (1966) found that *C. felis* populations were higher on mongooses during the cooler and more moist months on the island of Hawaii (December-July), coinciding with the mongoose breeding season. It is especially interesting that Cole and Koepke (1946) found that the number of cat fleas on Norway rats in Alabama actually increased during winter months. It is not know whether cat flea populations on feral hosts might serve as sources of infestation for domestic pests in the spring.

Table 2. Survey of domestic cats in Boston, Massachusetts from December to July 1914.[a]

Month	Mean No. Fleas/Cat
December	3.75
January	3.85
February	2.3
March	1.08
April	2.52
May	3.1
June	3.9
July	10.05

[a] 82% of the 139 cats infested with 1-30 cat fleas (Lyon 1915).

Animal surveys also indicate that the number of cat fleas on a host is generally low and the number of female fleas outnumbers the males. Osbrink and Rust (1985) found that about 70% of the cats had either no fleas or less than 7 fleas and about 10% of the cats inspected had greater than 50 fleas per animal. Similarly, Kristensen et al. (1978) reported that an average of 6.3 fleas per cat, but a median of only 2 fleas per animal inspected (n=82). High numbers of ectoparasites are often a sign of illness, generally not the cause of it (Marshall 1980).

Studies in which groups of fleas were confined in small cages to the neck of cats showed that the average life expectancy of adult male and female cat fleas to be 11.8 and 7.2 days, respectively (Osbrink and Rust 1984). Collections of eggs from adult fleas on cats also showed that by week 4 egg production had decreased nearly 65% with practically no egg production by week 6. There are reports of adult longevity of up to 185 days when fed on humans for 15 minutes per day and held in containers at 75% RH (Bacot 1914). If we understood the precise nature of the differences between these experiments, then we might possibly understand how flea populations overwinter adverse environmental conditions.

There may also be interactions between 1st- and 2nd-order environmental factors. Excess droplets of blood produced by the adult flea feeding on the host serve as food for the developing larvae. Studies by Bruce (1948) indicated that dried blood or blood components such as albumin, hemoglobin, and fibrin were essential for larval development. Consequently, it is extremely important that these droplets of dried blood accumulate in 2nd-order environments suitable for egg and larval development. The quality or suitability of host (resistance or immunity) may have an extremely important bearing on the success of developing larvae.

Most animal surveys indicate that adult cat fleas are present on the host throughout the year. In light of the adult longevity on the host and developmental requirements of immatures, many questions arise regarding how populations might survive unfavorable conditions. A cursory review of the literature summarized in Table 3 reveals several strategies utilized by several species of fleas to overwinter harsh conditions. The pre-emerged adult sand martin flea, *Ceratophyllus styx jordani* Smit, remains in the cocoon from November until March waiting for the return of migrating sand martins to the nesting ground. Similarly, the hen flea, *Ceratophyllus gallinae* (Schrank) and the blackbird flea, *Dasypsyllus gallinulae* (Dale), overwinter as adults in cocoons in old nest material, but they migrate from the nest in search of new hosts in the spring (Bates 1962). Some species of adult fleas belonging to *Xenopsylla* or *Archaeopsylla* overwinter as free adults in the host's burrow. Reduced feeding on hibernating hosts has been reported and Marshall (1981) observed some reductions in flea feeding during the winter on nonhibernating laboratory animals. Certain species of fleas are active when hosts are hibernating such as several species of *Nycteridopsylla* on bats (Reisen et al. 1976). It is not known exactly how cat fleas overwinter in northern latitudes. These or other mechanisms may be operating to ensure adult fleas will survive winter and infest the host in spring.

Table 3. Summary of some mechanism utilized by various species of fleas to overwinter harsh environmental conditions.

1. Adult flea remains in the cocoon

   sand martin flea, *Ceratophyllus styx jordani*

2. Eggs overwinter in grass

   Dorcadia spp. found on sheep

3. Overwinter as free adults in burrows

   Xenopsylla spp. in rodent burrows
   Archaeopysllа erinacei on hedgehogs

4. Adults active on hibernating hosts

   Nycteridopyslla spp. on bats

Recommendations for the control of cat fleas frequently include treatment of the animal, the indoor environment and areas surrounding the home. Many of these recommendations have not taken into consideration the importance of 1st- and 2nd-order environments on the development of the cat flea. There needs to be a greater awareness and emphasis of these factors in our pest management programs.

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CAT FLEAS, CTENOCEPHALIDES FELIS, IN SCANDINAVIA: PREVALENCE, PROPHYLAXIS AND CONTROL

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The Danish Pest Infestation Laboratory (DPIL) under the Ministry of Agriculture was established 40 years ago. Due to the public service which at present gives advice to an average of 0.7% of the Danish households, material for early warnings against new pests introduced and the relative prevalence of pests in households and farms is obtained. The advisory service also helps in finding households for field experiments concerning biology of the pests and efficacy of control measures.

During the seventies it became obvious that Danes were facing a new problem of fleas on cats and dogs. An escalating number of inquiries to the DPIL showed this fact, the fleas on pets becoming the single pest with the most frequent inquiries. Also, the veterinarians were aware of this new pest due to the escalating numbers of pets suffering from flea dermatitis (Steen Kristensen, 1979)

The Ph. D. thesis of Kristensen tells that Danish families every summer have an overall risk of 33% to get their pets infested with fleas. Roughly 10% of the flea infested pets will develop flea allergic reactions. Thus, the flea ectoparasites have become the primary factor causing dermatological problems.

At that time there were many wrong conceptions concerning the life of the cat flea. Knowledge from the rat flea and the human flea was thought to cover even the cat flea. Fleas were told to live for years, to survive extreme conditions, and pets getting fleas were said to bite themselves to clean off the fleas which were supposed to jump off to lay eggs in the environment. Many of these misconceptions have now been corrected by accurate knowledge of the cat flea biology and host adaptation; others are still to be investigated. - The cat flea has a very tight association with the fur of its hosts. This makes the cat flea unable to mate and produce eggs if not staying permanently in the fur taking frequent bloodmeals. Most cats and dogs are not troubled much by their cat flea ectoparasite. Thus, cats and dogs can easily sustain a cat flea population without human awareness. At DPIL Niels Dyhr Christensen started to look close into the biology of the cat flea asking the question: Would it be possible to eradicate the cat fleas by manipulating the indoor climate? The answer, no, came at the same time as the Silverman & Rust team published their paper on that subject (Silverman 1981).

Gunvor Brinck-Lindroth (1983), was the first to draw attention to the new coming cat flea problem in Sweden. Neither Norway nor Finland suffer from a cat flea problem and are not expected to do so in the future as the winters are too cold and thus the humidity indoors often becomes too low. Furthermore, the population density is low.

The reason for the escalating flea problem in Denmark during the seventies is not proven. However, plausible reasons are proposed and at least two changes during that time which obviously would favour the increase of the cat flea population are known. Firstly, the number of pets has escalated in advance of the cat flea boom. A trend of the influence of the escalating pet population is found by comparing the number of pedigree dogs and the "flea index", i.e. the percentage of cat flea inquiries of the total inquiries to the DPIL, from the sixties till now. Whether or not the parallel curves represent a causal relationship is not proved but it is plausible. Pedigree dogs covers about 1/10 of the total population of dogs. Secondly, the increasing habit of covering the floors in homes with wall-to-wall carpets gives the flea larvae a better possibility to live and develop, compared to older times uncovered hard floors.

As soon as the outdoor temperature goes below 10°C the humidity goes below 55 % RH indoor. This causes difficulties in the cat flea reproduction due to poor survival of the juvenile flea larvae. Survivors reproduce during the spring and summer and the frequency of inquiries reaches a maximum during the months of August to October. The infestation of cat fleas on feral cats shows the same pattern, an almost 100 % infestation during the months of August to October declining to a minimum infestation during April.

Urban entomology problems in Denmark are mainly due to indoor pests and around 50% of the value of the private sale of pesticides is for this purpose. Below is the use of indoor insecticides seen tabulated for comparison on a time scale:

INDOOR USE OF PESTICIDES IN DENMARK

YEAR	Compounds no.	Compounds value	1000 kg	1000 ai kg	Collar	Premises								
Groups of insecticide					1 DIBROM	2 CARB	3 PROP	4 OC	5 PYR	6 Syn	PYR	7 OP	8 JHA	9 *
1)1977	167	18	852	36				*	*					
1)1978	193	22	814	46	*	*	*	*	*					
1)1979	203	24	724	41	*	*	*	*	*					
1)1980	240	25	764	23	*	*	*	*	*					
2)1981	97	11	91	4.3	*	*	*	*	*	*				
2)1983	97	15	159	7.6		*	*	*	*	*				
2)1984	86	14	134	5.1		*	*		*	*	*	*		
2)1985	88	16	122	4.5		*	*		*	*	*	*	*	
2)1986	98	12	156	5.3		*	*		*	*	*	*	*	

1) 1977-80 All indoor compounds grouped together
2) 1981-86 Compounds against pests on household animals and their premises
Data from Annual Reports / Ministry of Environmental Protection
Pesticide Department

Abbreviations: CARB = carbaryl
PROP = propoxur
OC = organochlorine compounds
PYR = pyrethrum
Syn PYR = synthetic pyrethroids
OP= organophosporous compounds
JHA= juvenile hormone analoques

Comments on the various groups of insecticides used in Denmark for cat fleas, retrospectively:

1) The fumigating flea collar containing Dibrom, naled, (3.3 g a.i.for dogs) was introduced 1978, called "4 month collar" .
Collars were tested on flea infested dogs in private households during 1981 comparatively with propoxur flea collars. The overall reduction in the flea counts 3 week post treatment was 94% when using propoxur flea collars and 34% when using Dibrom. Therefore the agent stopped marketing the much less effective Dibrom collar.

2) & 3) Carbaryl and propoxur flea collars were introduced to the Danish market at the same time as the Dibrom collar, called "3 month" & "5 month" collars respectively.
These collars were tested in field studies during the 1980 flea season. The efficacy of new collars when tested alone and combined with the traditionally used compound for the premises at that time, methoxychlor, was investigated.
The carbaryl collars had an efficacy too poor to get an approval. Dog owners had a chance of 50% to get rid of fleas when using a new carbaryl collar and cat owners had just 33% chance to get their cats to a zero flea count, 3 weeks after the collar treatment was started. The chance of getting rid of fleas by using new propoxur collars were 80% and 70 % respectively for dogs and cats.

4) & 5) Organochlorine, methoxychlor, sprays with and without pyrethrum were tested in combination with collars for the pets and as premise sprays solely. Only 30 % of the flea infested dog houses and 14% of the cathouses were found flea free when treating houses with 1 g of a.i of methoxychlor per m^2. No alternative compound for the premises was available at that time.

6) Formulations of permethrin were tested in field trials during the flea season 1981. When used at a rate of 50 mg / m^2 the product was efficient in combination with propoxur collars. Therefore, the product was approved in this combination.

7) During the late summer and autumn of 1982 a kerosene pump spray with diazinon was tested in a field trial comparatively to treatment with methoxychlor and propoxur flea collar. The new product, used at a rate of 0.5 g per m^2 for the premises and pets given just a wash with a pyrethrum shampoo, gave no signs of fleas at the evaluation 3 week post treatment out of 20 test families. The control group given propoxur flea collars and methoxychlor for the premises, 4 of 19 families still had signs of fleas. Accordingly, and due to comparatively lab. tests, the diazinon product was approved and the approval of the methoxychlor product was withdrawn.

During the flea season of 1981 the fumigation strips containing DDVP, dichlorvos, were tested in privat premises. They proved effective in eradicating the active stages of fleas but had no effect on fleas in the cocoons. The treatment dosage was 1 strip (104 g 18.6%) per 30-60 m^3. The product is not registered for this purpose due to toxicological considerations.

8) Preliminary tests were run during 1982 to evaluate the efficacy of methoprene as a premise spray. Families at a high risk of getting flea problems were used as test families. Ten dwellings were treated during the last week of June and the first week of July given approapproximately 3.4 mg per m^2. Small carpet roundels were treated by the time of treating the houses and checked 0, 2, 4 and 11 weeks post treatment for the development of adult fleas when these treated roundels were infested with 10-20 flea larvae. Of the 240 samples infested with flea larvae only one adult flea developed. One family in the test group had a flea problem which needed an additional treatment. In the untreated control group of 10 households two had used propoxur collars prophylactically. Seven families in the control group had observed fleas to which they had made an traditional adulticide treatment. Based on this result and on supplementary lab. trials showing that 20 ppb methoprene, when mixed in the larval food, prevent adult development, methoprene was officially recommended for profylactic treatments of premises at risk of sustaining cat flea breeding.

9) During the winter 1983-1984 an additional effect of the juvenile hormone analogue methoprene, the ovicidal effect on cat flea eggs when treating fur of cats and dogs, was discovered (Olsen 1985). The first cat treated was given 26 mg a.i. methoprene which prevented flea eggs from hatching more than a month under lab. condition. Trials also from field studies show that total prevention of flea eggs from hatch is achieved by using 25 mg each fortnight which is more efficient than treating the double dosage once a month. Small dogs are recommended the same dosage as cats. Medium and big dogs are recommended the double dosage. Under this recommendation the product was approved and sold for the prevention of building up flea populations for the first time during the flea season of 1985.

Recently, and not previously published, is was shown that other insect growth regulators as the juvenile hormone mimic S31183 and even the chitin synthesis inhibitor diflubenzuron (Dimilin) has persistent ovicidal activities on cat flea eggs, when used as a fur treatment of flea infested cats.

The new methods of preventing flea build up by prophylactic treatments have still to wait for its practical application in the most cat flea troubled countries. It has been used since 1985 in Denmark. This alternative method of preventing build up of flea problems by treating just the pets might have an extra advantage in climates sustaining an outdoor flea breeding. Also, ovicides might be used in strategies for preventing development of resistance. After an ordinary adulticide treatment, ovicidal treatment might prevent the resistant survivors to reproduce.

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MANAGEMENT OF STORED PRODUCT INSECTS WITH PHEROMONES

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Introduction

We now have available the pheromones for many of the important stored product insects. Research during the last 20 years has emphasized the isolation and correct identification of the pheromones. While studies with stored product insects have perhaps lagged behind those of field crop orchard or forest pests, the potential for pheromones in the stored product environment is perhaps greater. The reason for this optimism is that in contrast to field crops or forests, the stored product environment usually requires zero or low tolerance for insects. Pheromones are effective at low population levels and offer the possibility of finding insects earlier than with conventional searching methods.

A general discussion of insect pheromones for urban pest management was provided by Bell (1986) at the first National Conference on Urban Entomology. The objectives of this paper are to review the current status of the use of pheromones for management of stored product insects and to stimulate discussion on new directions for research. I will restrict most of my remarks to examples with beetles, the subject of my research.

Pheromones of Stored Product Insects

The functions of pheromones in stored product insects follow two general patterns. These are sex pheromones for the short-lived adult insects and aggregation pheromones for the long-lived adult insects (Burkholder, 1982). The short-lived adults usually do not feed, and the females nearly always produce sex pheromones. The long-lived adults feed and the males usually produce aggregation pheromones, although females of such species may also produce sex pheromones. For practical trapping efforts the aggregation pheromones are especially useful, because both male and female insects respond, whereas sex pheromones usually attract only the opposite sex. A brief summary of these pheromones follows. A more detailed review was presented by Burkholder and Ma (1985).

Dermestidae The aldehyde component of the *Trogoderma* spp. sex pheromone (Cross et al., 1976) has been used extensively by the food processing industry for detection and monitoring of adult males. This pheromone has been used successfully both inside and outside food processing and storage facilities. The males of most species of *Trogoderma* are excellent fliers, especially when they are outside of buildings. Research is needed to determine how far they fly. These beetles will live outside in wasp nests as far north as Wisconsin. Females are not good fliers, however, after some of their eggs are laid and their fat body has been depleted flight is more easily attained. It should be noted that the males emerge from several days to a week before the females. We have successfully trapped males in pheromone traps and, based on the location of the trapped insects in the food processing plant, located the Trogoderma infestation which consisted primarily of female pupae. Prompt cleanup and treatment resulted in satisfactory control. Continued pheromone trapping is always recommended as a monitoring technique. The USDA Animal and Plant Health Inspection Service (APHIS) and the State of California use the Trogoderma pheromone for detection and monitoring the khapra beetle, Trogoderma granarium Everts, a quarantined pest. The Anthrenus spp. and Attagenus spp. carpet beetle pheromones have been identified but not commercialized.

Anobiidae The cigarette beetle (Lasioderma serricorne (F.)) sex pheromone (Chuman et al. 1979) has been studied extensively in recent years and is now available, with traps, for monitoring in food or tobacco facilities. Faustini (1988) presented evidence that these traps were superior monitors when compared to blacklight traps. He suggested that a major barrier to overcome in the establishment of a pheromone program in an industrial environment was the development of an educational and training program. He believes that when pheromone traps are used in conjunction with intensive sanitation and selective pest control programs, a substantial reduction in target pests results.

The drugstore beetle (Stegobium paniceum (L.)) sex pheromone (Kuwahara et al., 1975, 1978) has recently been made available for monitoring with traps. The same pheromone is produced by female furniture beetles, Anobium punctatum (de Geer) (White and Birch, 1987). Based on this information, monitoring traps would be expected to catch both species if they are present. It is unclear how species specificity in mate attraction occurs.

Bostrichidae The male-produced aggregation pheromones of both the lesser grain borer, Rhyzopertha dominica (F.), (Khorramshahi and Burkholder, 1981 and Williams et al. 1981) and the larger grain borer, Prostephanus truncatus (Horn), Hodges et al. 1984) are known. These pheromones are available and have been used for detection and monitoring. The lesser grain borer pheromone has been particularly useful in monitoring migration of the insects outside of grain bins.

Cucujidae The male-produced aggregation pheromones of the Cryptolestes spp. (flat and rusty grain beetles) and Oryzaephilus spp. (sawtoothed and merchant grain beetles are known (Pierce et al., 1984). They are not commercially available.

Curculionidae Males of the rice weevil, Sitophilus oryzae (L.), and its congener, the maize weevil, S. zeamais Motschulsky, produce the same aggregation pheromone (Phillips et al. 1985, Schmuff et al. 1984). The pheromone is attractive to both sexes of these two species, as well as to the granary weevil, S. granarius (L.). Males of the granary weevil produce a structurally similar aggregation pheromone (Phillips et al. 1987).

Tenebrionidae The male-produced pheromone of both the red flour beetle, Tribolium castaneum (Herbst), and the confused flour beetle, T. confusum Jacquelin du Val, was identified by Suzuki (1980). The racemic pheromone has been available and the pure RR isomer is expected to be available soon.

Bruchidae Males of the bean weevil, Acanthoscelides obtectus (Say) produce a sex pheromone (Horler, 1970). The pheromone is not commercially available.

Pyralidae Females of the Indianmeal moth, Plodia interpunctella (Hubner), and the almond moth, Cadra cautella (Walker), produce a sex pheromone that is attractive to the males of these species and several other moth species. The Indianmeal moth female produces a second component that increases male attraction but is inhibitory to male almond moths (Sower et al. 1974).

Management With Pheromones, Food Attractants and Traps

Pheromones were used in multilayered corrugated paper traps for trapping dermestid beetles (Barak and Burkholder, 1976, Burkholder, 1976) and for the lesser grain borer (Williams et al. 1981). The corrugations serve as ideal harborage sites and provide circulation for the lures. The early version of the trap utilized insecticides to kill the attracted insects. Barak and Burkholder (1985) improved the trap by utilizing a vegetable-oil based food attractant instead of insecticides for killing the insects. The attractive oil lures suffocate the insects when they fall or crawl into the receptacle. The oils, which incorporate a combination of mineral-, oat- and wheatgerm oils, are combined with pheromones to attract both adults and larvae. These traps have been commercialized and are available from Trece Inc.

An insect trap was made from an inverted, flat bordered, plastic weighing boat by Lindgren et al. (1985). It contained eight inward-projecting, conical depressions. The traps, with pheromones, were used for trapping Cryptolestes ferrugineus (Stephens) and T. castaneum in controlled environment chambers. Funnel traps have been used to trap dermestid beetles (Shapas and Burkholder, 1978) and moths (Cogan and Hartley, 1984). The wing or delta-type sticky traps are useful in trapping moths and flying beetles. A metal probe trap devised by Loschiavo and Atkinson (1967) and one made of plastic and developed by Burkholder (1984) are adapted for use in grain.

The plastic grain probe trap was used successfully with the aggregation pheromone of the lesser grain borer to catch the grain borers in bagged sorghum (Leos-Martinez et al., 1987). Lippert and Hagstrum (1987) used the plastic probe traps to detect and estimate insect populations in bulk-stored wheat. Insect infestations of wheat stored on 20 Kansas farms were estimated with the traps and with 0.265-kg deep-bin cup (seedburo) samples. For the four most common species, traps were 1.7- to 2.6-fold more likely to detect an infestation than the cup samples. They concluded that the probability of detection can be improved by using more traps.

The plastic traps were developed for use in combination with pheromones and food attractants, yet work exceptionally well without them. It appears the daily movement of the insects results in their interception by the traps. The insects then fall through the specially designed slanted holes into the bottom of the device. Cracked wheat, other cracked grains, or wheat germ oil are being used as food lures. The upper end of the trap contains a plastic tube or rod suitable for holding pheromone or food lures. The trap therefore is not only physically attractive and effective in catching insects, but can also hold food and pheromone baits for additional attractance. Moisture that condenses on the traps may also attract some insects. For those insects that produce aggregation pheromones, the trapped insects may also serve to attract others. The grain weevils will not produce pheromones unless food is present.

In laboratory trapping studies with the maize weevil, cracked wheat was a stronger attractant than either whole wheat, wheat germ oil, or water, and a strong synergistic effect between the (4S,5R) isomer of the pheromone and cracked wheat was also demonstrated (Tables 1 and 2) (Walgenbach et al., 1987).

Table 1. Comparative responses of maize weevils to dispenser cup attractants in corrugated cardboard traps

Dispenser cup attractant	$\bar{x}$ catch
Cracked wheat	15.4c
Whole wheat	7.1b
Wheat germ oil	2.3a
Water	2.1a

Four-choice test, eight replicates, 100 2- to 10-d-old maize weevils per replicate. Means followed by the same letter do not differ signficantly ($P > 0.05$; Duncan's [1955] multiple range test, based on mean square from pooled row, column, and error). (Walgenbach et al. 1987).

Table 2. Maize weevil pheromone/wheat synergism in a four-choice test using corrugated cardboard traps

(4S,5R)-sitophinone	Cracked wheat	x catch
+	+	36.0c
-	+	14.8b
+	-	0.9a
-	-	0.0a

Four-choice test, eight replicates, 100 2- to 10-d-old maize weevils per replicate. Means followed by the same letter do not differ signficantly (P > 0.05; Duncan's [1955] multiple range test, mean square based on pooled row, column, and error sums of squares). (Walgenbach et al. 1987).

Maize weevils were successfully lured out of a grain source only when both cracked wheat and (4S,5R) pheromone isomer were present in the trap. For general trapping, certainly the cracked grain should be used. If specific insects such as the grain weevils are targeted, then pheromone lures should also be used to obtain maximum trapping efficiency. Further research on combining pheromones and food lures is in progress.

The value of the moth sex pheromone tetradecadien-1-ol acetate (TDA) to the food industry has been well established. It is the primary sex attractant for males of several species of stored product moths. Suss and Trematerra (1986) indicated that in Italy the pheromone has allowed workers to program control measures against these insects in the food industry and in stored products. They also reported that in some cases their use brought about a substantial reduction in chemical treatments.

Studies by Wohlgemuth et al. (1987) in Germany demonstrated that pheromone traps caught male *Plodia interpunctella*, *Anagasta kuehniella* (Zeller) and *E. elutella* (Hubner) out of doors. *Cadra cautella* was missing from the traps, presumably because of a lack of the specialized food they require. In specially baited traps (pheromone and broken almonds) and in the vicinity of heavily infested objects, a very small number of female moths was also caught. Cogburn et al. (1984) has also trapped lesser grain borers outside bins. Trap catches around the bins were inversely proportional to the height of the traps. Cogburn (personal communication) reports that pheromone traps will always catch *R. dominica* in field and forested areas some distance from the grain storage areas. *T. glabrum* males as well as other dermestids are easily trapped outside (Shapas and Burkholder, 1978). These results and others show that stored-product insects occur outside of storage facilities. Traps for monitoring insects in grain should be deployed just following harvest. Monitoring should be a continuous process until the grain is moved to the next destination. Particular care should be taken following treatments, such as fumigations, to assess their effectiveness. Traps should also be used prior to harvest to determine if residual populations of insects are present. Traps should be placed both outside and inside the bins. Traps outside the bins should be monitored following harvest as freshly harvested grain is a strong attractant for insects.

Placement of traps in warehouses is dependent in part on the size of the building and the available supporting posts. Generally the traps should be placed at least in the corners and near the walls and supporting posts. Interior areas should trapped in a grid pattern if possible to monitor all areas. Careful checking of trapping records is necessary. If one area appears to have an infestation additional traps may be used to pinpoint the infestation to a particular bag or package. It is important not to neglect continued monitoring of all areas to determine the effectiveness of sanitation programs. Care should be taken to keep traps away from open doors and windows to prevent insect entry to the premises. It is recommended that traps also be placed outside buildings to trap migrating insects. Traps can be placed on fences, posts or other places approximately 20 to 30 m from the building. Additional information on trap placement was reported by Burkholder (1984) and Mueller (1985).

The use of pheromones to attract insects to pathogens, insecticides, hormones or other bioactive compounds is promising. Shapas et al. (1977) demonstrated that Trogoderma glabrum could be attracted by its female sex pheromone to a source of pathogenic protozoa, Mattesia trogodermae, to create an epizootic. The use of kairomones to manipulate parasitoids also demonstrates considerable promise in the stored products environment.

Summary

The use of pheromones to detect, monitor and control stored product insects has great potential. Much more research is needed to provide information relating trap catch to infestation levels and on additional novel suppression techniques similar to that in which the insects are inoculated with a pathogen. In urban systems the use of traps containing non-toxic baits is useful and now possible with the use of food oils as both attractants and killing agents. The traps need to be effective, safe, easy to use and low in cost. Education programs need to be developed on the value and use of pheromones and traps. Perhaps the greatest value of attractants is their safety and effectiveness.

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INSECT GROWTH REGULATORS IN URBAN PEST MANAGEMENT

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Insect growth regulators (IGRs) have been very successful in the Urban Pest Management arena, with uses for fleas, the German cockroach, mosquitoes, the pharaoh ant and stored product pests. Some of the more recent developments with IGRs and some of these pests will be discussed here, with an emphasis on the German cockroach.

German Cockroach - *Blattella germanica* (L.)

Methodologies used in the experiments discussed here have been cited in the published literature (Bennett et al. 1986, King and Bennett 1988, Runstrom and Bennett 1984).

Laboratory Studies - Tables 1 and 2 show that fenoxycarb resulted in significantly higher mortalities than hydroprene (both applied at 10 µg/µl) to 1st and 4th instar nymphs, and significantly higher levels of sterility to virgin females, fertilized females and males, respectively. The sterility effects of fenoxycarb to fertilized females and the mortality effects to 1st stage nymphs are particularly notable.

Table 1. Mean percent mortality of German cockroach nymphs following topical exposure to fenoxycarb or hydroprene.[a]

Treatment & dosage (µg/µl)	x % mortality[b] Age at exposure (nymphal stage) 1st	4th
Fenoxycarb 10	90.0[a]	76.7[a]
Hydroprene 10	33.3[b]	6.7[b]
Control	10.0[b]	0.0[b]

[a]From King and Bennett 1988

[b] Within each column, percentages followed by the same letter are not significantly different (P > 0.05; Newman-Keuls range test [Anderson and McLean 1974]).

Table 2. Reproductive effects of fenoxycarb and hydroprene applied topically to German cockroach adults [a,b].

Treatment &dosage μg/μl	% Sterile[c]		
	Virgin females	Fertilized females	Males
Fenoxycarb 10	56.7[a]	93.1[a]	43.3[a]
Hydroprene 10	0.0[b]	32.1[b]	7.1[b]
Control	13.3[b]	20.6[b]	13.7[b]

[a]All treated cockroaches were paired with a non-treated mating partner.

[b]From King and Bennett (in press).

[c]Within each column, percentages followed by the same letter are not significantly different (P > 0.05; Newman-Keuls range test).

Wing twisting of females was not 100% correlated with sterility at the 10μg/μl doses of fenoxycarb and hydroprene (Table 3). At the lower treatment rates, some wing twisting occurred, but a significant decline in sterility was found with hydroprene.

Table 3. Relationship between wing-twisting and sterility among IGR-treated German cockroach females[a].

Treatment & dosage (μg/μl)	x twisted wing-rating[b]	% of twisted-wing females sterilized[c]
Fenoxycarb 10	3.5	96.1[a]
Fenoxycarb 1	1.8	69.2[a]
Hydroprene 10	3.0	96.2[a]
Hydroprene 1	1.6	27.7[b]

[a]From King and Bennett (in press).

[b]Twisted-wing ratings based on 0-5 scale.

[c]Within each column, percentages followed by the same letter are not significantly different (P > 0.05; Newman-Keuls range test).

Findings from this study show fenoxycarb to induce greater mortality (through the inhibition of molting), sterility and morphogenetic effects than hydroprene. Fenoxycarb appears to be a promising candidate for pest management programs against *B. germanica* because it sterilizes late instar nymphs as well as adults, and causes mortality in younger nymphs.

Several experimental chitin synthesis inhibitors are being evaluated in laboratory studies. Tables 4 and 5 present LC_{50} and LC_{95} data for 2nd and 5th stage German cockroach nymphs. All of these compounds show promise with UC 84572 and CGA 112913 causing nymphal mortality at very low concentrations. This information is exciting relative to the future of IGRs in German cockroach management.

Table 4. Lethal Concentrations of chitin synthesis inhibitors (% a.i. in diet) required to kill 2nd stage nymphs of the German cockroach[a].

Compound	N	LC_{50}[b]	LC_{95}
Dow XRD-473	300	0.019[a]	0.077[a]
Alsystin	300	0.027[a]	0.145[a]
UC 84572	240	0.000508[b]	0.00119[b]
CGA 112913	180	0.000191[c]	0.000425[c]

aThanks to J. J. DeMark for the use of his data.

bWithin each column, numbers followed by the same letters are not significantly different (95% FL).

Table 5. Lethal Concentrations of chitin synthesis inhibitors (% a.i. in diet) required to kill 5th stage nymphs of the German cockroach[a].

Compound	N	LC_{50}[b]	LC_{95}
Dow XRD-473	300	0.765[a]	3.82[a]
Alsystin	300	0.649[a]	3.57[a]
UC 84572	240	0.000754[b]	0.00139[b]
CGA 112913	180	0.000363[c]	0.000562[c]

[a]Thanks to J. J. DeMark for the use of his data.

[b]Within each column, numbers followed by the same letters are not significantly different (95% FL).

Field Studies - Hydroprene causes a gradual decline in a population because sterile adults die without producing offspring. Laboratory studies have shown fenoxycarb to have additional mortality and sterility effects. With this in mind, let's review field evaluations of various treatment strategies using these 2 JHAs.

In 1982, Dursban/Vaponite + 1.2% hydroprene, Dursban/Vaponite alone, and 1.2% hydroprene alone were applied to cockroach infested apartments and monitored over a 6-mo period (Fig. 1). The insecticide/IGR combination declined gradually over time from > 90% to < 80% population reduction. The IGR alone treatment did not show significant population reduction until after 3 mo, demonstrating the importance of a supplemental insecticide treatment in achieving rapid reductions in populations.

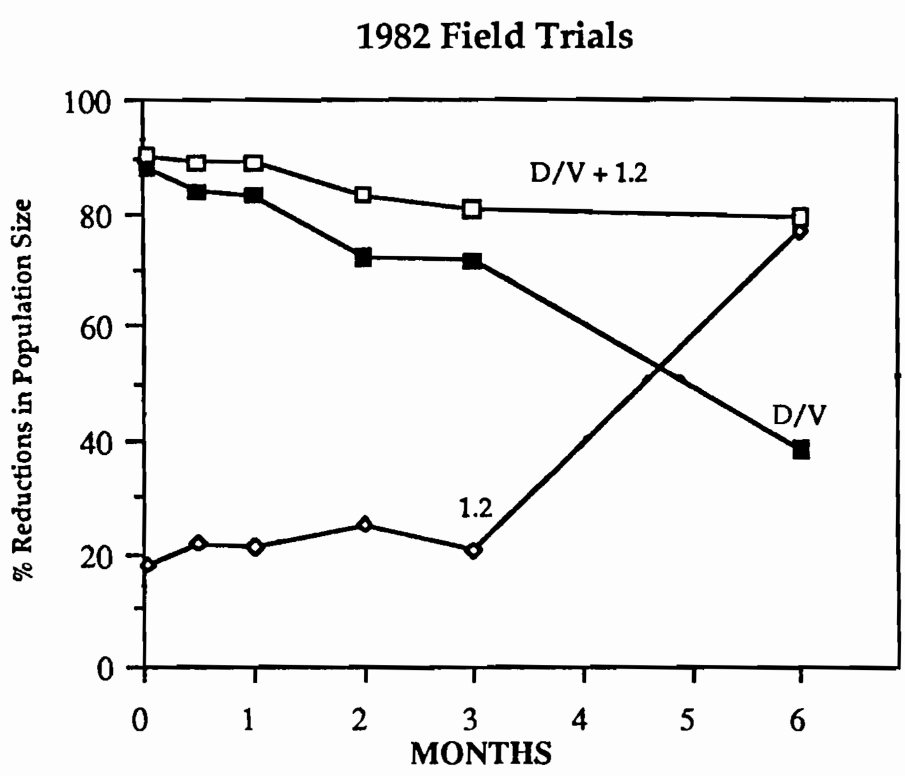

Fig. 1. Mean percent reductions of German cockroach populations in apartments after treatments with Dursban/Vaponite + 1.2 % hydroprene (D/V + 1.2), Dursban/Vaponite (D/V) or 1.2% hydroprene (1.2). All Dursban/Vaponite treatments were applied at the 0.25%/0.25% rate.

Fig. 2 represents mean percent population reductions over 12 mo using several treatment and 3-mo retreatment strategies. Using this low rate (0.6%) of hydroprene was not effective in these experiments, even when a retreatment with both Safrotin and hydroprene was made. When compared with the 1.2% hydroprene treatment and retreatment strategy shown in Fig. 3, significantly higher population reduction are noted over the 12-mo evaluation period for the 1.2% treatment. Sterility in the 1.2%-treated population, as reflected by the mean percent twisted-wing adults (Fig. 4), was significantly higher following the 3-mo retreatment than any of the other treatment/retreatment strategies. This emphasizes the need for the higher rate of hydroprene in treating buildings with heavy cockroach infestations. The percent adults with twisted wings declined significantly for all treatments by 12-mo (Fig. 4), pointing to the need for retreatment every 2-3 mo.

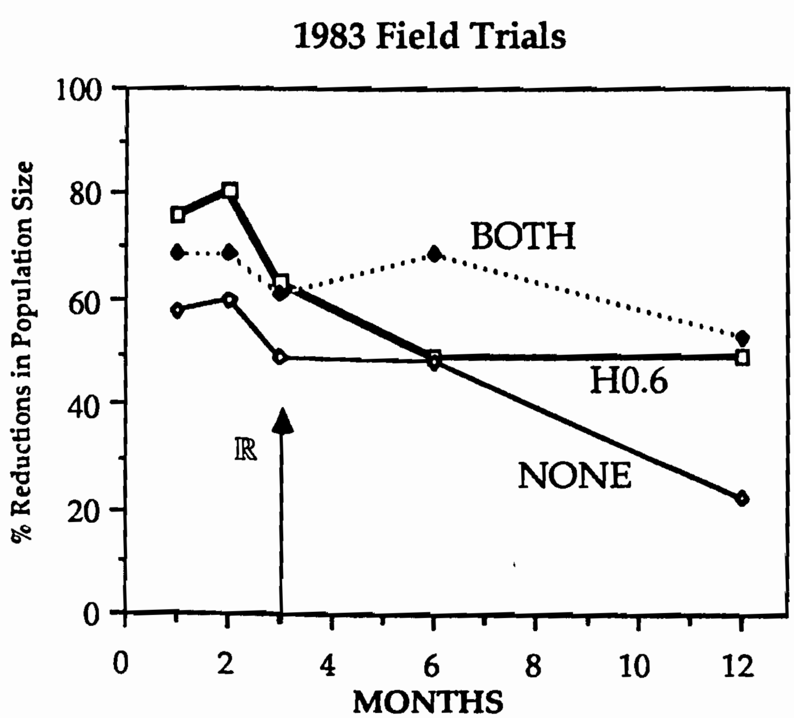

Fig. 2. Mean percent reductions of German cockroach populations in apartments after treatments with 1.0% Safrotin + 0.6% hydroprene and 3-month retreatments with 1.0% Safrotin + 0.6% hydroprene (BOTH), 0.6% hydroprene (H0.6) or no retreatment (NONE).

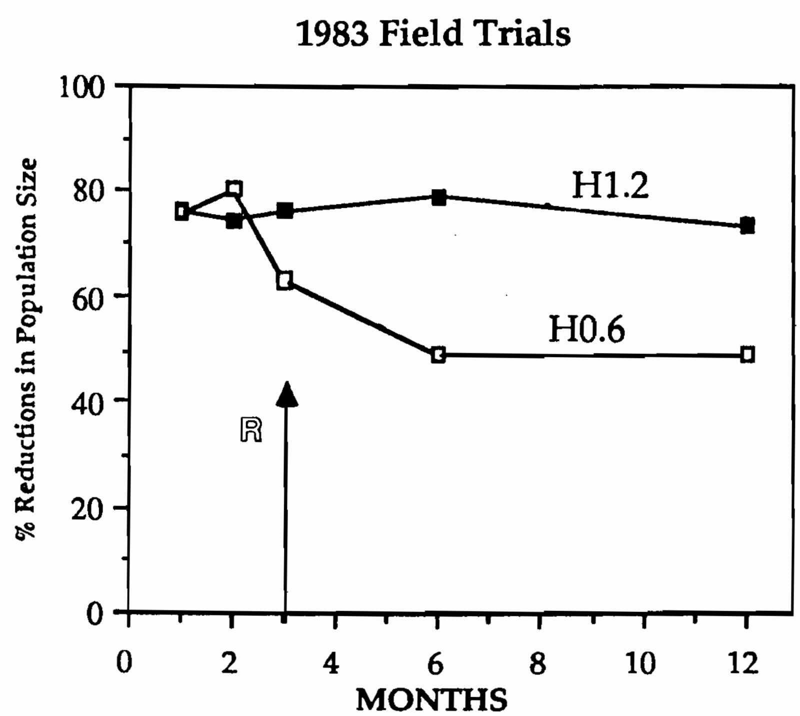

Fig. 3. Mean percent reductions of German cockroach populations in apartments after treatments with 1.0% Safrotin + 1.2% hydroprene (H1.2) and 1.0% Safrotin + 0.6% hydroprene (H0.6). Three-month retreatments were 1.2% hydroprene (H1.2) and 0.6% hydroprene (H0.6).

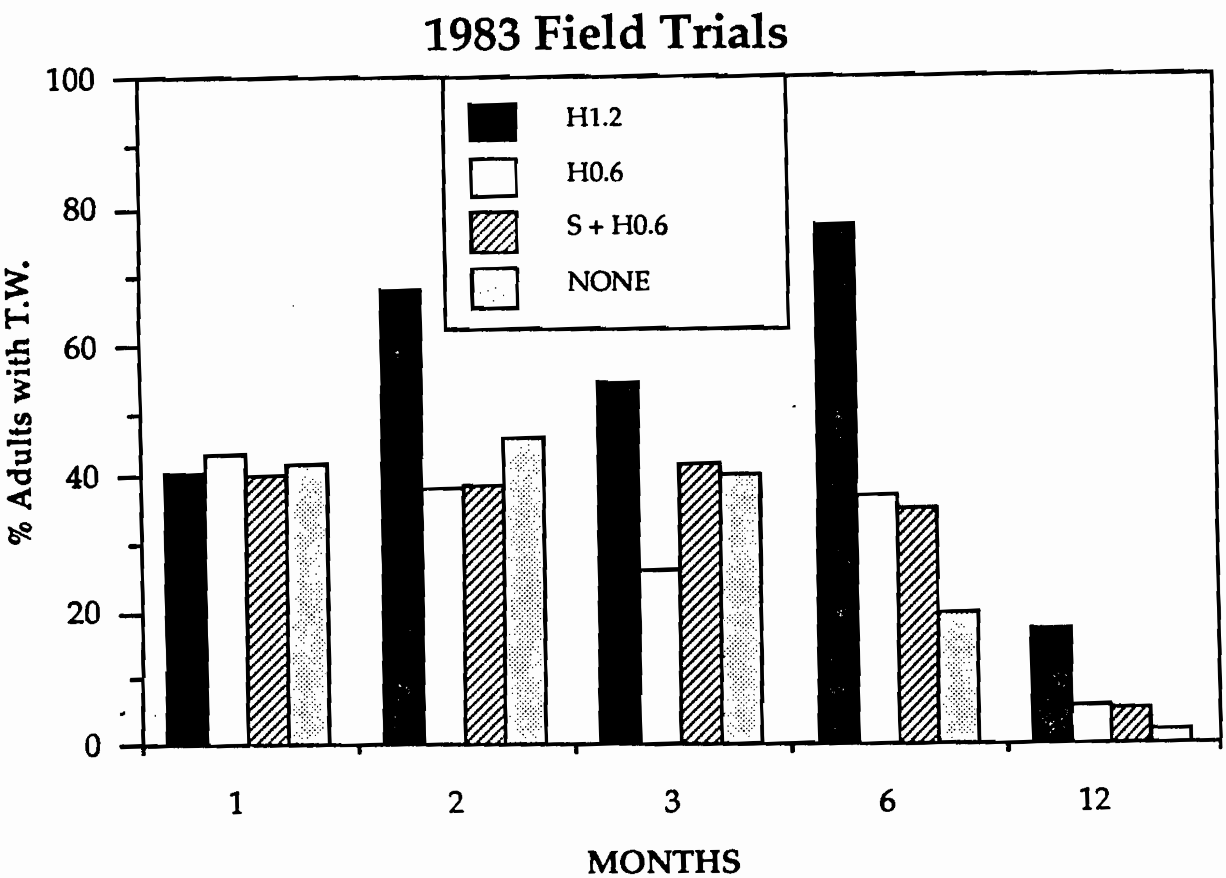

Fig. 4. Mean percent of German cockroach populations as twisted-wing (T.W.) adults in apartments with initial treatment/3-month retreatment as follows: 1.0% Safrotin + 1.2% hydroprene/1.2% hydroprene (H1.2); 1.0% Safrotin + 0.6% hydroprene/0.6% hydroprene (H0.6); 1.0% Safrotin + 0.6% hydroprene/same 3-month retreatment (S + H0.6); and 1.0% Safrotin + 0.6% hydroprene/no 3-month retreatment (NONE).

Fenoxycarb treatment strategies (Fig. 5) were evaluated in field experiments in 1986. The 1.0% Safrotin alone treatment/retreatment strategy was the least effective over the 12-mo evaluation, with 10-25% lower population reductions than the fenoxycarb treatments at the various post-treatment evaluation periods.

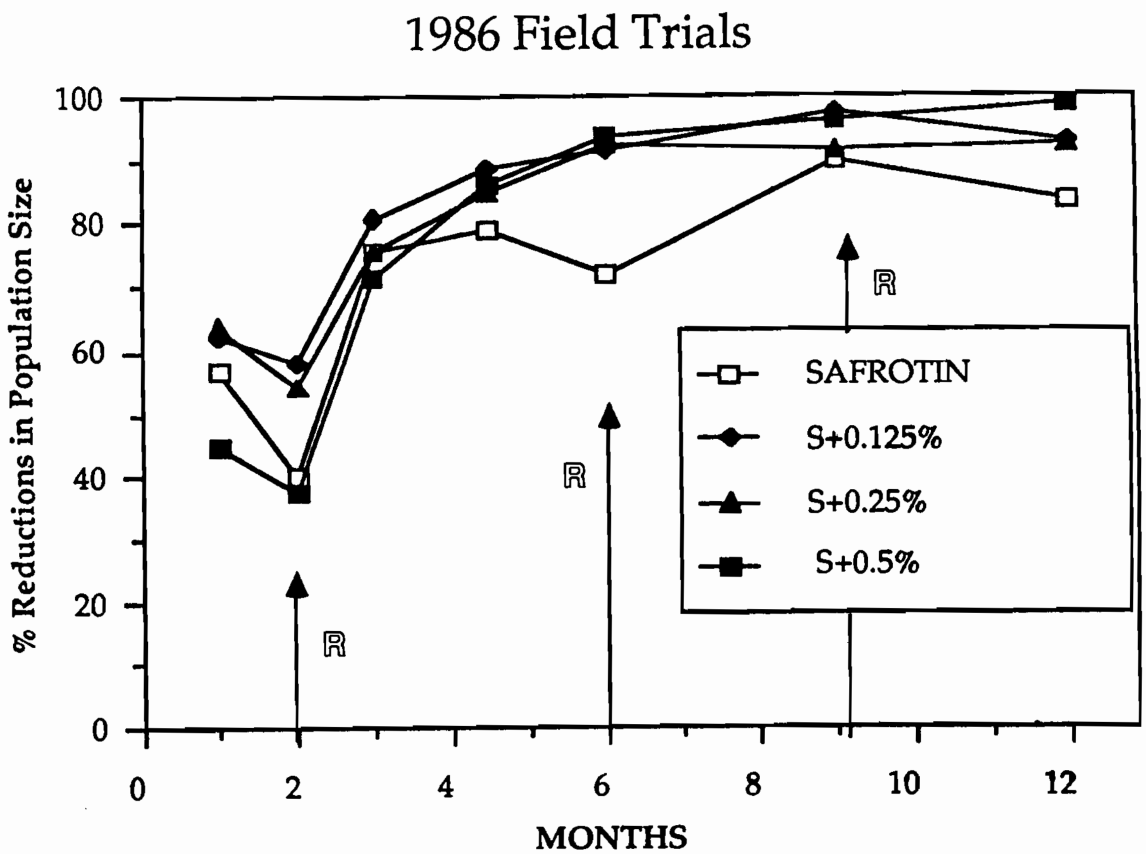

Fig. 5. Mean percent reductions of German cockroach populations in apartments treated and retreated at 2, 6, and 9 month intervals with 1.0% Safrotin (SAFROTIN), 1.0% Safrotin + 0.125% fenoxycarb (S + 0.125%), 1.0% Safrotin + 0.25% fenoxycarb (S + 0.25%), and 1.0% Safrotin + 0.5% fenoxycarb (S + 0.5%).

All 3 rates of fenoxycarb evaluated were effective, with less than 10% difference in population reductions between the high and low rates. In evaluating population sterility (% adult wing twisting), Fig. 6 shows that the 0.5% rate of fenoxycarb resulted in consistently higher levels of wing twisting over the 12-mo evaluation periods. The importance of maintaining population sterility at high levels for best long-term results cannot be overemphasized. In fact, subsequent field trails with a 0.06% application rate of fenoxycarb resulted in failure to achieve adequate population reductions. Considering the low levels of sterility attained by the 0.125% rate (Fig. 6), this unsatisfactory result with the 0.06% rate could be predicted.

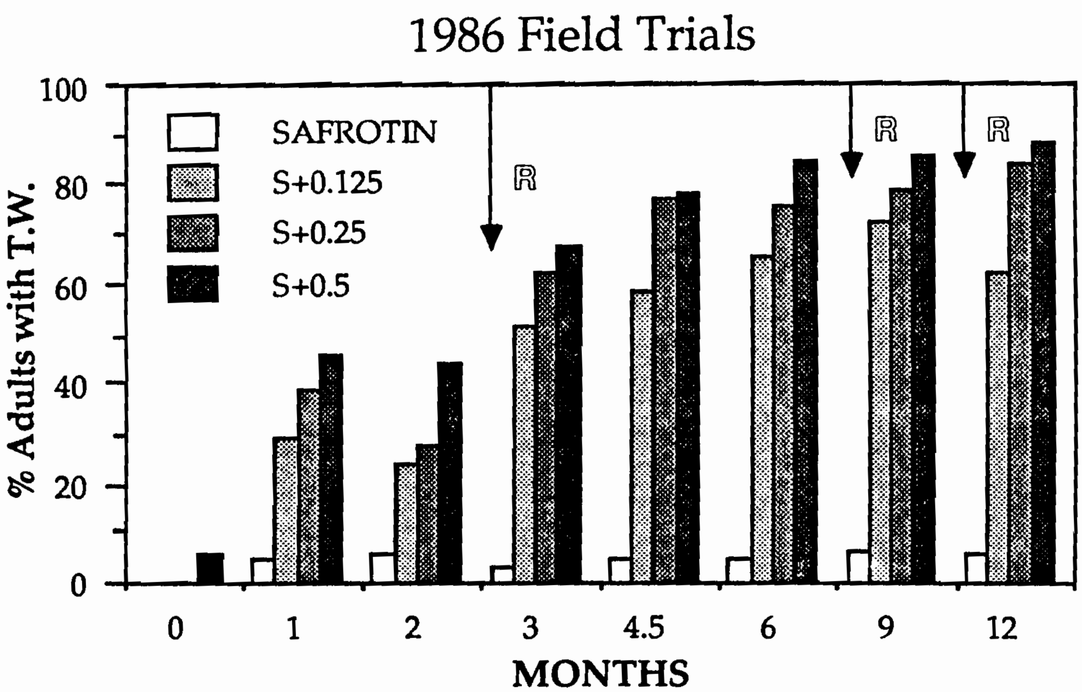

Fig. 6. Mean percent of German cockroach populations as twisted-wing (T.W.) adults in apartments following treatment and 2, 6, and 9 month retreatment with 1.0% Safrotin or 1.0% Safrotin and 3 different rates of fenoxycarb.

JHAs are excellent candidates for use in long-term German cockroach management strategies. Rates of application and appropriate retreatment intervals (at least every 3 mo) are critical considerations in formulating successful programs. JHAs are not appropriate for all German cockroach problems, but in buildings with serious and chronic infestations, JHAs have their greatest utility. IGRs (including JHAs, molting inhibitors, chitin synthesis inhibitors, etc.) are considered biorational chemicals; thus, many of the negatives associated with the continuous use of insecticides, such as resistance and contaminating residues can be alleviated through the appropriate use of IGRs.

Thanks are expressed to B. L. Reid for his assistance in the analysis and preparation of these field data for this presentation.

Fleas and Termites

Methoprene has been used successfully in flea control programs for many years. In recent laboratory tests, fenoxycarb and methoprene were applied to pieces of carpet and evaluated against 1st instar cat flea larvae for the inhibition of development. Table 6 shows that there was sufficient residual activity with either chemical to provide season-long protection from fleas.

Table 6. IGR inhibition of larval cat flea development[a].

		% emerged adults from deposits aged:			
Treatment	(%)	1 da	4 wks	20 wks	52 wks
Fenoxycarb	0.125	0	0	0	10
	0.0312	0	0	7	20
	0.0078	0	10	17	57
Methoprene	0.015	0	0	10	40
	0.0078	0	0	3	53
Untreated		67	87	93	93

[a]Thanks to M. K. Rust for the use of his data.

The role of IGRs in termite control is not yet known. Methoprene, fenoxycarb, and a numbered compound (Ro 16-1295) have been studied in the lab (Su et al. 1985). Mortality of worker termites has generally been low (< 20%) and not much higher with soldier termites (< 40%). One interesting phenomenon has been the formation of presoldiers from IGR-treated workers. This shift from worker to presoldier could have pronounced impact on the social integration (worker ratio) of a termite colony, leading to eventual colony demise. Additional information is also needed on the transport of IGRs to queen termites, and the sterility that might result. Thus, a number of questions must be answered before the utility of IGRs for termite control will be known.

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INTERNATIONAL ASPECTS OF URBAN PEST MANAGEMENT: COCKROACH PESTS IN CHINA

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The goal of the National Conferences on Urban Entomology was to bring together urban entomologists from research, extension, and industry for the exchange of data and ideas on a variety of insect pests (Zungoli 1986). It is appropiate that emphasis be given to pests and pest management programs in the United States in the first two conferences, but the scope must eventually be expanded. The worldwide distribution of many household and structural pests can provide for a considerable amount of information exchange between scientists. Limited research funds available to academia and industry should promote increased exchange of biological and control data on common pests. The research and pest management programs on household and structural insect pests outside the U.S. include:

[] scientists in Denmark and England have provided considerable data on the biology, habits, and control of the cat flea (Olson 1982, Olson et al. 1982);

[] researchers in Hungary, and West Germany, are working on cockroach biology and control (Bajomi and Erdos 1982, Klunker 1977);

[] mosquito abatement and stinging insect control are research topics in England and Europe (Curtis and White 1984, Burgess 1986, Delmotte and Mathot 1983);

[] scientists in West Germany, Japan, France, and Yogoslavia are working on the biology and control of beetles infesting structural wood (Kuhne 1981, Iwata and Nishimoto 1980, Cymorek 1968, Guillemain-Thevenot et al., 1972, Marovic 1976).

Complete reviews of the urban-pest research programs worldwide would be valuable, but not possible in one presentation. Indeed, an International Conference on Urban Entomology would be required--and at this time may be very appropiate!

I will limit this presentation to a review of some of the research and pest management programs for household cockroach pests in China--The People's Republic of China. China's research community is perhaps the least known throughout the world, primarily because of the language differences, and the isolationist policy that has historically characterized the government.

CHINA

Background. The People's Republic of China is a vast and geographically varied country. The population is nearly one billion, with about 240,000 million people living in urban areas. Associated with the living space for this population is a variety of household and structural insect pests; the most important include mosquitoes, termites, bedbugs, and cockroaches.

There are approximately 19 cockroach species that are household pests in China. The major pest species are *Blattella germanica* (L.), and six *Periplaneta* species. The major *Periplaneta* species include *P. americana* (L.), *P. australasiae* (F.), and *P. fuliginosa* (Serv.). The German cockroach occurs primarily in locations that are regularly heated in winter, such as hotels, restaurants, and transportation stations (Woo and Guo 1984). *Periplaneta* species are more generally distributed, and occur in single- and multiple-family dwellings (Woo 1982).

Research on Cockroaches. Research on cockroach pests in China is conducted primarily at the government level--the Ministry of Agriculture, the Chinese Academy of Sciences, branches of the military, especially the Navy, and the Anti-epidemic and Sanitation Stations. There is a limited amount of research conducted at the university level (Gafford 1981). Not unlike the U.S., there are limited funds available to university-based scientists for research on household and structural pests. The agency primarily responsible for research on cockroach biology, insecticide resistance, and the design and delivery of cockroach pest management programs in China is the Anti-epidemic and Sanitation Stations. There are Anti-epidemic and Sanitation Stations located in all provinces and major cities. Leadership for the cockroach research efforts is provided by Dr. Xiu-yuan Hu; he is stationed in Nanjing.

The Anti-epidemic and Sanitation Station personnel involved in cockroach and bedbug research form a "scientific study group"; this group of about 150 professionals meets once a year to exchange information and plan research projects. Most of the research data presented at these meetings has been compiled in three books (Huang 1986). These volumes contain 90% of the published data on cockroaches in China in the last 10 years. Unfortunately, these books are not well known, and have a limited distribution. 1987 marked the 10th year for the scientific study group, and the annual meeting was held December 8-12 in Shanghai. Approximately 150 professionals from all over China, including Anti-epidemic and Sanitation Station personnel and People's Patriotic Health Committee personnel, gathered to present research data and discuss pest management programs for cockroaches and bedbugs.

A review of some of the cockroach pest management programs discussed at this meeting can provide some insight into the typical design and delivery of such programs in China.

COCKROACH PEST MANAGEMENT IN DALIAN

The coastal city of Dalian is located in northeastern China in Liaoning Province. This large city covers 12,000 square kilometers, and is a leading port and tourist attraction. In 1987 the city government declared that they wanted the city to be "cockroach free". A technical advisory committee was formed to design a program to achieve this. It was composed of representatives from a medical college, a university biology department, the Anti-epidemic and Sanitation Station, and the People's Patriotic Health Committee. The funds for the program were provided from the central and provincial governments.

Pest Management Program. The technical advisory committee set out to design a cockroach pest management program that would be accepted by the people, easily carried out, and effective in reducing the cockroach infestation level. The program was composed of 1) a survey of cockroaches and structures, 2) establishment of infestation-level goal, 3) selection of insecticides, 4) an education program, 5) chemical and nonchemical control strategies, and 6) evaluation procedures.

The program has a three-year action plan. In 1987 emphasis was placed on control structures with serious cockroach infestations; in 1988 the program will be expanded to the entire city; in 1989 the program will be evaluated, and long-term control strategies will be considered.

Survey. The Anti-epidemic and Sanitation Station employed and trained 600 people to inspect the living space of 17,000 families for cockroaches. The survey revealed six cockroach species as pests in the city. *P. japonica* (98%) and *B. germanica* (2%) were the most common, and 51% of all structures were found to be infested. In one instance, Station personnel removed 3.6 kilograms of dead cockroaches from one structure. Visual, sticky trap, and flushing methods were used in the survey of the target pests. Kitchens (68%) were found to be the most infested area, and second was outside storage rooms (9%). The structures with the highest incidence of cockroaches were more than 16 years old.

Infestation-level Goal. The goal of the program was to achieve within three years the goal of 5% or less of the apartments and houses containing five or fewer cockroaches, and 2% or less of the apartments and houses containing two or fewer cockroach egg cases.

Control Strategies. During the initial survey, cockroach harborage sites were noted. For the first phase of the program three truckloads of concrete were used to seal cockroach harborages discovered in the initial survey.

Candidate insecticides were screened and permethrin selected for the first indoor spraying in April of 1987. In June and August permethrin and cypermethrin were applied indoors, and dichlorvos and permethrin were applied outdoors. All application were made by Anti-epidemic Station personnel and people trained by them.

Evaluation. The pest management program as evaluated in October 1987. Living areas were inspected by professionals using a 3% pyrethrins spray directed in suspected cockroach harborages. At the end of the first year 90% control was reported.

COCKROACH PEST MANAGEMENT IN SHANGHAI

The seaport city of Shanghai is one of the world's largest cities with about 17 million people. There are about 4 million families, and 2 million live in central city.

A survey for cockroaches revealed that there were infestations in a majority of the buildings. A pest management program similar to the one in Dalian was prepared.

The cockroach pest management program in Shanghai involves the Anti-epidemic and Sanitation Station and personnel from the People's Patriotic Health Committee. These two groups work closely in implementing the program. The Anti-epidemic Station personnel are usually university-trained professionals. They provide the design and direction of the program, but they may have limited contact with the residents--the target audience. The Patriotic Health Committee personnel are less trained, but they implement the program, and interact directly with the residents.

Following a survey of structures to determine the level of household infestations, candidate insecticides were screened using field-collected cockroaches, and applications made by the Anti-epidemic Station personnel and the 2,400 people employed and trained for pest control. An additional 1,700 people were employed to maintain and evaluate the program. The budget for pest control in the city of Shanghai is Y5 million ($18 million) per year.

The goals for the Shanghai program are similar to those for Dalian: 5 or less cockroaches in family living spaces; 3 or less cockroaches in food stores, and hotel kitchens; and 0 cockroaches in restaurants, and hotel lobbies and rooms. A fine of Y10-Y20 is imposed when infestation levels exceed these goals. The Anti-epidemic Station personnel are responsible for this regulatory action.

CONCLUSIONS

Cockroach pest management programs in China are well planned and almost always successful. For a country with so many people and crowded conditions in many of the urban areas, successful pest management programs are important! Much of the success comes from the level of organization, the availability of a large workforce, and the government, district, community, and individual cooperation possible in a socialist country.

The organizational structure of the program in Dalian is an excellent example. The technical advisory group provided leadership to a subgroup that contacted and trained the professional pesticide applicators, and a second subgroup organized and instructed the leaders and people in each city district. The district communist leaders, in turn, contacted leaders at the community/apartment/commercial building level, they contacted individuals and explained the program. Education programs with one-to-one contact can be very effective (Thoms and Robinson 1986). The success of the program is partly due to the involvement and committment of local governments.

Pest management programs for household or nuisance pests in the U.S. are often hampered by limited funds and workforce, changing or disinterested leadership, and limited education programs for the target audience. The success of the programs in China is evidence of what can be accomplished when some of these variables or obstacles are removed.

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Abstracts of Paper Presentations

TERMITES

Penetration Abilities of Dursban® TC into Pine Sapwood. B.L. Dodson, W.B. McCloud & Company, Schaumburg, IL 60193

Residual amounts of Dursban® TC, a termiticide containing chlorpyrifos, when applied to pine sapwood will remain relatively constant six months after the initial treatment at depths of 400-600 microns below the wood's surface. The wood moisture content of treated wood did not significantly influence the penetration abilities of Dursban® TC at tested moistures.

Termiticides Today. J.K. Mauldin and M.K. Bradford, FS-USDA, Southern For. Exp. Sta., Gulfport, MS 39503

The chemicals available for subterranean termite control are changing. The highly effective termiticides, chlordane and heptachlor, are under serious review by the Environmental Protection Agency. Since 1980, chlorpyrifos, isofenphos, endosulfan, permethrin, fenvalerate, and cypermethrin have been registered as termiticides. Effectiveness of these chemicals in nationwide tests will be given.

New Technologies for Control of Drywood and Subterranean Termites. W. Ebeling, Dep. Biol., Univ. California, Los Angeles, CA 90024 and C.F. Forbes, Dep. Earth Sci., California State Univ., Dominguez Hills, CA

Tarp-covered buildings are heated to 150°F to bring interiors of structural wood members to 120°F, lethal to drywood termites. Light, flexible ducts conduct heated air throughout the building and a heat-resistant fan in every room prevents heat stratification. Sand (10-16 mesh) is a barrier against subterranean termites.

Can Termite Bioassay Procedures be Standardized? J.K. Grace, Facul. For., Univ. Toronto, Toronto, Ont. Canada M5S 1A1

Standardization of materials testing procedures is an ideal with universal support, but also universal failings due to geographic differences in biology, environmental conditions, and specific goals. From work with Reticulitermes, the author suggests that acceptance of a standard theoretical approach to material evaluation may be of more value than attempts to standardize methodological details.

Variables Which Influenced Tunnel Location in the Eastern Subterranean Termite *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae). J.B. Ballard, Dow Chemical, Moorestown, NJ 08057

Variables were evaluated in terms of their ability to influence tunnel location in eastern subterranean termites. Termite workers initiated tunnels wherever vertical surfaces were encountered. On a slanted soil surface, tunnels were initiated at the bottom of the slant.

Wood-destroying Insects in Louisiana During 1987. J.P. La Fage, Dep. Entomol., Louisiana State Univ., Baton Rouge, LA 70803

In Louisiana, pest-control operators perform nearly 40,000 treatments for wood-destroying insects (wdi) annually. State law requires that every treatment be recorded with the Louisiana Department of Agriculture and a contract for work performed be issued to the property owner and recorded by the Structural Pest Control Commission. Beginning in 1987, the Department of Agriculture expanded its record keeping procedures so that the contract report included additional information. Data now compiled includes name of property owner, address of property treated, date of treatment, type of insect treated, construction type, an type of treatment (preconstruction, remedial, spot).

An analysis of treatment records for the year 1987 is in progress. Data on the first seven months of 1987 reveal that slightly more than 20,000 wdi treatments were performed in the state by licensed pest-control operators. Of these, the vast majority (ca. 20,000) were for native subterranean termites. Many fewer contracts were written for Formosan subterranean termites than had been expected. Four times as many slab construction treatments were performed than pier treatments. Remedial treatments outnumbered preconstruction treatments by three to one. The accuracy of the data collected is highly dependent upon the knowledge and concern of the person filing contract for the pest-control operator. Future efforts will be concentrated on verifying data already compiled and establishing actual costs associated with types of treatments performed.

COCKROACHES

Age Dependent Developmental and Morphogenetic Responses of Last Stage German Cockroach Nymphs to Fenoxycarb and Hydroprene. J.E. King and G.W. Bennett, Dep. Entomol., Entomology Hall, Purdue Univ., W. Lafayette, IN 47907

Bioassays were conducted to determine the sensitive developmental period of last stage German cockroach nymphs to topical applications (10 μg/μl) of fenoxycarb and hydroprene. Both juvenoids induced wing-twisting and sterility among adults treated during the first half of the last instar. In addition, fenoxycarb killed nymphs treated on day 6 and sterilized over one-half of the cockroaches treated only 3-4 days before the final molt.

Comparative Toxicology and Biochemical Detoxification Capacity of North American Blattella Species. **R.W. Wadleigh[1], P.G. Koehler and R.S. Patterson[2], [1]Household Insect Research Project, Univ. Florida, Institute of Food an Agricultural Sciences, Gainesville, FL 32611; [2]USDA-ARS, Insects Affecting Man and Animals Research Laboratory, P.O. Box 14565, 1600 SW 23rd Dr., Gainesville, FL 32604**

Insecticide toxicity and biochemical detoxification capacity were studied in Blattella germanica (L.), B. vaga Hebard, and B. asahinai Mizukubo. Comparative studies are reported on organophosphorus, carbamate, and pyrethroid insecticide toxicity data and the results of assays of insecticide detoxification systems in these species.

Vapor-Induced Behavior in Different Strains of the German Cockroach, Blattella germanica (L.). **M.T. Wooster and M.H. Ross, Dep. Entomol., Virginia Polytechnic Institute and State Univ., Blacksburg, VA 24061**

Behavioral bioassays were used to determine dispersal times for 50% of the German cockroach populations (DT50) in order to examine vapor-induced strain differences. Pesticide-susceptible and field-collected resistant strains were tested. Pesticides examined included: propoxur, diazinon, malathion and S-Bay FCR.

Laboratory Evaluation of the Flushing Activity and Knockdown Effect of Insecticides for German Cockroach Control. **B.L. Reid and G.W. Bennett, Dep. Entomol., Purdue Univ., W. Lafayette, IN 47907**

An inexpensive laboratory test procedure was developed to assess the flushing effect and knockdown activity of insecticides used to control the German cockroach, Blattella germanica (L.). The number of insects which leave the harborage (= flushed) and that exhibit moribund symptoms (= knockdown) are monitored repeatedly for one hour after treatment. This procedure provides a relative measure of blatticide flushing and knockdown activity, and may be predictive of results under field conditions.

Control of Cockroaches Around Bryan, Texas Homes with Insecticidal Treatments During 1987. **T.A.. Granovsky, Granovsky Associates, Inc., 3206 Wilderness Rd., Bryan, TX 77801**

Effective perimeter treatment of urban homes can reduce populations of Periplaneta spp. and Parcoblatta spp. cockroaches which can invade at ground level. A 1/2% Dursban bait provided significantly more and longer cockroach control than Dursban 50W, Dursban 1/2% Granules, Dursban ME, or Knox Out 2FM. Insecticidal treatments around the exterior of urban Texas homes is important for cockroach management.

The Role of Diet Composition in Determining Feeding Response of the Brown-Banded Cockroach (*Supella longipalpa*) to Insecticide Treated Diets. **R.W. Hamilton and C. Schal, Dep. Entomol., Rutgers Univ., New Brunswick, NY 08903**

Longevity, reproduction, and daily meal size were examined in female brown-banded cockroaches fed diets containing either 5%, 25%, 65% protein or commercial rat food. Based upon these consumption patterns, feeding rates and mortality were examined in insects fed the 5% and 25% protein diets which were treated with either boric acid or hydromethylnon. Boric acid inhibited the feeding response to a large degree, while diets containing hydromethylnon were consumed at rates equal to control diets. Feeding rates were enhanced on a diet low in protein and high in carbohydrate. However, these minor differences in feeding patterns were not sufficient to cause changes in mortality rates of insects fed insecticide treated diets.

URBAN IPM PROGRAMS

Urban IPM and the Structural Pest Control Industry. **C.M. Christensen, Dep. Entomol., Univ. Kentucky, Lexington, KY 40546**

The structural pest control industry has traditionally been a service industry centered around the regular application of pesticides. The industry has utilized calendar applications of pesticides to economically provide a reasonable level of pest control in past years but the emerging challenges of contamination, pesticide resistance, and public "right to know" threaten this type of pest control service. Pest management tools and techniques exist that will allow the industry to implement truly integrated pest management programs. The economics of implementing IPM programs is the major difficulty.

The Urban Clientele: Opportunities for IPM Programs. **J.R. Gladin, Dep. Entomol., Oklahoma State Univ., Stillwater, OK 74078-4064**

Increasing awareness of pesticide usage in the urban environment has fostered interest in providing IPM programs for the urban clientele. Accessing these clients can be difficult due to the lack of organization. However, they can be reached through extension programs and the distribution of materials using appropriate channels. Two programs conducted in Oklahoma are recent examples.

An IPM Index for Household Cockroach Control. **A.J. Slater, Office of Environmental Health and Safety, Univ. of California, Berkeley, CA 94720**

Data gathered over eighteen years from 920 student apartments was used to develop an IPM index. The index is a compilation of effectiveness, safety, and costing factors and is used to measure and compare different control strategies to plan management decisions for the future. This concept can be used in other UIPM programs.

Quality Assurance in Integrated Pest Management. G. Million, Veterans Administration Medical Center, Fort Howard, MD 21052

Quality assurance is the "cutting edge" of improved management for a diverse group of services and businesses. The role and methodology of quality assurance and its relationship to Integrated Pest Management is discussed. Many of the concepts addressed are applicable to pest management operations in a wide range of settings.

Biologically-Based Cultural Control Methods; Outdoor Cockroaches and Migrating Millipedes. A.G. Appel, Dep. Entomol., Auburn Univ., Auburn, AL 36849-5413

Most cultural control methods are based on little more than educated guess-work. For outdoor cockroaches, Periplaneta species, and migrating millipedes, Oxidus gracilis Koch, desiccation studies revealed rapid water loss (cuticular permeabilities range from 45 to 80 $\mu g/cm^2/h/mmHg$), little desiccation tolerate, and decrease movement after desiccation. Habitat modifications alone reduced pest populations 70-90%.

Efficacy of Sulfuryl Fluoride and Admixtures of Carbon Dioxide Against the Cigarette Beetle, Lasioderma serricorne (Coleoptera: Anobiidae). W.L.A. Osbrink, N.-Y. Su and R.H. Scheffrahn, Fort Lauderdale Research and Education Center, Univ. Florida, Fort Lauderdale, FL 33314

Fumigations were conducted to determine the effectiveness of sulfuryl fluoride and admixtures of carbon dioxide against various life-stages of the cigarette beetle. Ovacidal effects of sublethal applications of the fumigant are presented.

An Integrated Pest Management Program for Indoor Pests in a Biomedical Research Facility. H.B. Jacobi and F.E. Wood, National Institutes of Health, Bethesda, MD 20896

An IPM program for indoor pests in research environments is presented. This program resulted in an 87% reduction in pest population levels and a 93% reduction in insecticide usage. Program components; i.e., monitoring, pest suppression strategies, record-keeping, and program evaluation are discussed.

NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

February 21-24, 1988

Adult Education Center
University of Maryland
College Park, Maryland

PROGRAM

Sunday, February 21, 1988

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

Monday, February 22, 1988

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

8:45 a.m. . . . . .Morning Session . . . . Auditorium
Local Arrangements - Gene Wood, University of Maryland
Introductory Comments - Michael Rust, U.C. Riverside

9:00 a.m. . . . . .Urban Entomology Perspectives . . . . Auditorium
Jeff La Fage, Louisiana State University
Bill Robinson, VPI & SU

10:00 a.m.. . . . . . .Urban IPM Programs . . . . Auditorium
Gene Wood, University of Maryland

10:40 a.m.. . . . . . .Break

11:00 a.m.. . . . . . .Arnold Mallis Memorial Lecture . . . . Auditorium
Studies on Lyme Disease
Gail Habicht, SUNY at Stony Brook

12:00 Noon. . . . . .Luncheon. . . . . Chesapeake

1:15 p.m.. . . . . . . .Afternoon Session . . . . Auditorium
Moderator - Claude Thomas, B&G Equipment

1:15 p.m.. . . . . . . .Foraging & Distribution of Subterranean Termites
Susan Jones, U.S. Forest Service, Gulfport

1:45 p.m.. . . . . . . .Foraging & Distribution of Cockroaches
Rick Brenner, USDA, Gainesville

2:15 p.m.. . . . . . . .Adjourn to Paper Sessions

2:30 p.m.. . . . . . . .Concurrent Paper Presentations

Termites 1105
Nan-Yao Su, Ft. Lauderdale REC, University of Florida - Moderator

2:30 . . Introduction
Nan-Yao Su, Ft. Lauderdale REC, Univ. of Florida

2:35 . . Penetration Abilities of Dursban® TC into Pine Sapwood
B.L. Dodson, W.B. McCloud & Company

2:47 . . Termiticides Today
J.K. Mauldin and M.K. Bradford, FS-USDA, Southern Forest Experiment Station

2:59 . . New Technologies for Control of Drywood and Subterranean Termites
W. Ebeling, U.C. - Los Angeles
C.F. Forbes, Dept. Earth Sci., Calif. State Univ.

3:11 . . Can Termite Bioassay Procedures be Standardized?
J.K. Grace, Facul. For., Univ. Toronto

3:23 . . Variables Which Influenced Tunnel Location in the Eastern Subterranean Termite *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae)
J.B. Ballard, Dow Chemical

3:35 . . Wood-destroying Insects in Louisiana During 1987
J.P. LaFage, Louisiana State Univ.

3:47 . . Closing remarks

Cockroaches. 1123
Coby Schal, Rutgers University - Moderator

2:30 . . Age Dependent Developmental and Morphogenetic Responses of Last Stage German Cockroach Nymphs to Fenoxycarb and Hydroprene
J.E. King and G.W. Bennett, Purdue Univ.

2:40 . . Comparative Toxicology and Biochemical Detoxification Capacity of North American *Blattella* Species
R.W. Wadleigh, University of Florida
P.G. Koehler and R.S. Patterson, USDA-ARS, Insects Affecting Man and Animals Research Laboratory

2:50 . . Vapor-Induced Behavior in Different Strains of the German Cockroach, *Blattella germanica* (L.)
M.T. Wooster and M.H. Ross, Virginia Polytechnic Institute and State University

3:00 . . Laboratory Evaluation of the Flushing Activity and Knockdown Effect of Insecticides for German Cockroach Control
B.L. Reid and G.W. Bennett, Purdue University

3:10 . . Control of Cockroaches Around Bryan, Texas Homes with Insecticidal Treatments During 1987
T.A. Granovsky, Granovsky Associates, Inc.

3:20 . . The Role of Diet Composition in Determining Feeding Response of the Brown-Banded Cockroach (*Supella longipalpa*) to Insecticide Treated Diets
R.L. Hamilton and C. Schal, Rutgers University

Urban IPM Programs 1109
Chris Christensen, University of Kentucky - Moderator

2:30 . . Urban IPM and the Structural Pest Control Industry
C.M. Christensen, University of Kentucky

2:40 . . The Urban Clientele: Opportunities for IPM Programs
J.R. Gladin, Oklahoma State University

2:50 . . An IPM Index for Household Cockroach Control
A.J. Slater, U.C. - Berkeley

3:00 . . Quality Assurance in Integrated Pest Management
G. Million, Veterans Administration Medical Center

3:10 . . Biologically-Based Cultural Control Methods; Outdoor Cockroaches and Migrating Millipedes
A.G. Appel, Auburn University

3:20 . . Efficacy of Sulfuryl Fluoride and Admixtures of Carbon Dioxide Against the Cigarette Beetle, *Lasioderma serricorne* (Coleoptera: Anobiidae)
W.L.A. Osbrink, N.-Y. Su and R.H. Scheffrahn, Fort Lauderdale Research and Education Center, University of Florida

3:30 . . An Integrated Pest Management Program for Indoor Pests in a Biomedical Research Facility
H.B. Jacobi, National Institutes of Health
F.E. Wood, University of Maryland

3:50 p.m. . . . . Concurrent Discussion Session

Termites 1105
Joe Mauldin, USDA-Gulfport - Moderator

Cockroaches 1123
Don Reierson, U.C. Riverside - Moderator

Urban IPM Programs
Ken Pinkston, Oklahoma State University - Moderator

5:30 p.m. . . . . Adjourn

Tuesday, February 23, 1988

8:00 a.m. . . . . Morning Session . . . . Auditorium

8:00 a.m. . . . . Pyrethroid Insecticides
John C. Wickham, Incon Consultants, Ltd.

9:00 a.m. . . . . Carpenter Ants
Roger Akre, Washington State University

9:30 a.m. . . . . Fleas
Mike Rust, U.C. - Riverside

10:00 a.m. . . . . . . Break

10:30 a.m . . . . Concurrent Discussion Sessions

Pyrethroid Insecticides 1105
Don Cochran, VPI & SU - Moderator
Presenters
John Proctor, Mobay Corporation
John Wickham, Incon Consultants, Ltd.

Ants 1109
Jimmy Olson, Texas A&M University - Moderator
Presenters
Robert Wagner, U.C. Riverside
Roger Akre, Washington State University
Ted Shapas, American Cyanamid Company

Fleas 1123
Richard Patterson, USDA-ARS, Gainesville - Moderator
SPECIAL PAPER - Alice Olsen, Danish Pest Infestation Laboratory
Presenters
Mike Rust, U.C. - Riverside
Dave Byron, B&G Equipment

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

Pyrethroid Insecticides 1105

Ants 1109

Fleas 1123

12:00 Noon. . . . . .Luncheon. . . . . Chesapeake

1:30 p.m.. . . . . . . .Afternoon Session . . . . Auditorium
Moderator - John Owens, S.C. Johnson & Son

1:30 p.m.. . . . . . . .Managing Stored-Product Insects with Pheromones
Wendell Burkholder, University of Wisconsin

2:00 p.m.. . . . . . . .Insect Growth Regulators
Gary Bennett, Purdue University

2:30 p.m.. . . . . . . .Information Transfer in Urban Extension
Michael Raupp, University of Maryland

3:00 p.m.. . . . . . . .Break

3:30 . . . . .Concurrent Discussion Sessions
Stored-Product Insects 1105
Dave Mueller, Insects Limited, Inc. - Moderator
Presenters
Wendell Burkholder, University of Wisconsin
Daryl Faustini, Philip Morris USA

Insect Growth Regulators .1123
Phil Koehler, Univ. of Florida - Moderator
Presenters
Gary Bennett, Purdue University
Mike Rust, U.C. - Riverside

Information Transfer in Urban Extension 1109
Bill Robinson, VPI & SU - Moderator
Presenters
Chris Christensen, University of Kentucky
Michael Raupp, University of Maryland

4:15 p.m.. . . . . . . .Repeat of Concurrent Discussion Sessions

Stored-Product Insects 1105

Insect Growth Regulators .1123

Information Transfer in Urban Extension 1109

5:00 p.m.. . . . . . . .Adjourn

6:00 p.m.. . . . . . . .Reception and Cash Bar

7:00 p.m. . . . . .Banquet . . . . Chesapeake

Master of Ceremonies - Mike Rust, U.C. Riverside
Speaker - Roger Gold, University of Nebraska
Recognition Award Recipients:
Dr. John Osmun, Purdue University
Dr. Gene Wood, University of Maryland

Wednesday, February 24, 1988

8:45 a.m. . . . . .Morning Session . . . . Auditorium
Moderator - Gene Wood, University of Maryland

8:45 a.m. . . . . .Historic Paths of Urban Development
Robert M. Adams, Secretary, Smithsonian Institution

9:45 a.m. . . . . .International Aspects of Urban Pest Management
Bill Robinson, VPI & SU

10:30 a.m. . . . . . . .Closing Remarks
Pat Zungoli, Clemson University

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ACKNOWLEDGMENTS

Special thanks to the following organizations who made contributions to this program:

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B&G CHEMICAL COMPANY
B&G EQUIPMENT COMPANY
CHEMPAR
DOW CHEMICAL COMPANY
NATIONAL PEST CONTROL ASSOCIATION
MELCO LABORATORIES, INC.
VELSICOL CHEMICAL CORPORATION
WOODSTREAM CORPORATION