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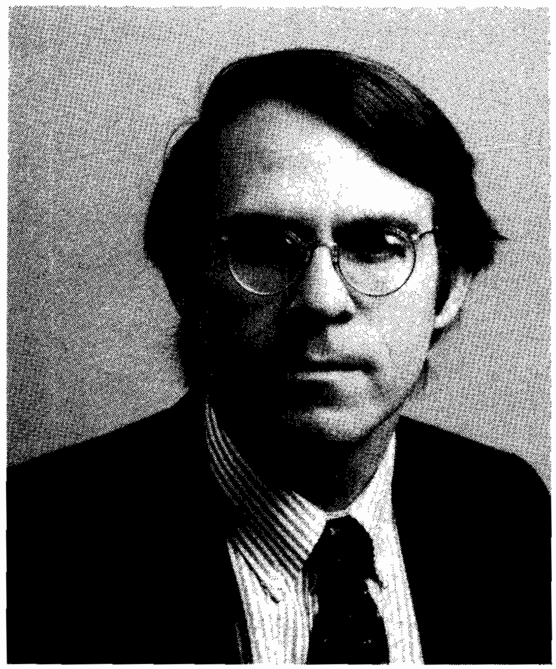
Dedication

We dedicate these proceedings to the memory of Jeffery P. La Fage.



Jeff La Fage dedicated much of his professional career and spirit to urban entomology and the industry served by this discipline -- the professional pest control industry. Were it not for his genuine interest in putting science into practice, Jeff would not have been in New Orleans working with pest control operators on termite control. His academic research was directed toward termite biology and habits, with emphasis on new methods of control.

Jeff's knowledge and extensive research program on the Formosan termite was recognized throughout the world. He had just been elected president of the International Research Group on Wood Preservation -- a group of scientists from around the world that provide leadership and direction to wood protection research. Some of the honors and recognition Jeff earned for his research and his perspectives on the discipline of urban entomology may have irritated some administrators. (Jeff was little concerned about recognition -- good or bad -- and was more concerned about the quality of the science that served the industry.)

He was an important contributor to the research base for urban entomology and the pest control industry. With those that shared his friendship, he shared his philosophy of serving the industry with good science. He had little patience for poor quality, and set high standards for himself. He encouraged all of us in academia to hold fast to our independence, and by that independence we would best serve society. Measure for measure, Jeff La Fage returned much more to his science and society than he took. Those of us in academia and the industry that knew him and worked with him learned from him and will not forget him.

NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

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CHEMICAL COMMUNICATION IN URBAN INSECTS

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ABSTRACT - Pheromones have been identified for many urban insect pests. These can be used in urban IPM programs for monitoring the presence of insect pests to time insecticide applications, and can be used in mass trapping or mating disruption programs for insect control. This chapter will discuss a few successful cases involving pheromones, as well as some cases that have potential for future use. Pests discussed in this chapter include the San Jose scale, Nantucket pine tip moth, clearwing borers, bagworm moth, the fire ant, yellowjackets, paper wasps, boxelder bugs, stored product pests, and cockroaches. A brief discussion also is presented on research we now are conducting on a volatile, long-distance sex pheromone of the brown-banded cockroach.

KEYWORDS - Pheromone, monitoring, mass trapping, IPM, brown-banded cockroach

INTRODUCTION

We have studied the pheromone communication systems in moths for over two decades, and have built up a knowledge base concerning the chemicals involved, their biosynthetic pathways and neurohormonal control of their production. Additionally we have investigated peripheral signal processing, behavioral responses to blends, and effects of neuromodulators, such as biogenic amines, on behavioral thresholds and odor discrimination. Although this program addresses fundamental questions in olfaction and reproductive biology, it also provides a basis for the practical application of pheromones in monitoring and control of pest populations (Ridgway, 1990). Our research has emphasized agricultural and forest pests, and so it was not clear what contribution I could make to this meeting of urban entomologists. After discussing this matter with several colleagues, however, I found that pheromones were playing an increasingly important role in urban entomology, and that our group had actually identified pheromones for a number of pest species that are a problem in the urban environment. Using information provided me by a number of colleagues, I would like to present several cases in which pheromones have been or potentially could be used in the urban environment. Additionally, I will briefly describe a new research project we initiated on the sex pheromone of the brown-banded cockroach.

IPM FOR SHADE TREE INSECT CONTROL

Pheromones have become an important tool in urban IPM programs for shade trees when used by knowledgeable personnel. Dr. Donald Booth, Entomologist at the Bartlett Tree Research Laboratories, Charlotte, North Carolina, has successfully implemented IPM programs in cities for a number of years. A few of his cases will be presented as examples of how pheromones can be used.

San Jose Scale

Although the San Jose scale, *Quadraspidiotus perniciosus* (Comstock), is a major and widespread orchard pest, it also has become a problem with cherry tree plantings in cities. In a letter from Dr. Booth to the arborist of Charlotte, NC, he states that they "examined the flowering cherry trees in downtown Charlotte. Most of these trees were found to be infested with San Jose scale. This insect has long, sucking mouthparts which penetrate bark and withdraw fluids from the tree. At first this feeding reduces plant vigor; heavy populations cause branch die-back and death of trees. .....control of this species has typically involved the use of many insecticide applications each year. In recent years several new approaches have been developed for San Jose scale control, including the use of pheromone traps and degree-day tables to accurately time treatments. Since the cherry trees in downtown Charlotte are difficult to spray and are in high human use areas, I have formulated an IPM Program incorporating recent research to control San Jose scale without the use of toxic synthetic chemicals. The aim of the program is to optimize control with the least number of sprays and to use the safest available treatments."

With the monitoring traps, applications of horticultural spray oil were applied once in each of the four generations of scale crawlers for control. It was fortunate in this case that the San Jose scale also is an important orchard pest and that the basic research on the pheromone monitoring traps had already been conducted. We had identified two pheromone components in 1979 (Gieselmann et al. 1979) and a third in 1981 (Anderson et al. 1981) in cooperation with researchers in California. Monitoring traps were developed for this pest and used to develop a scale phenology model to time subsequent crawler emergence (Rice et al. 1982; Rice & Jones 1988). The precise timing of the sprays has allowed pest managers in cities to use non-toxic spray oil, instead of more persistent, but toxic pesticides.

Nantucket Pine Tip Moth

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is one of a number of species in this genus that form a pest complex on ornamental and commercially grown pines. The Nantucket pine tip moth can be a pest in nurseries, Christmas tree and regeneration pine plantations, ornamental pines, and seed orchards. We investigated the pheromone of this moth, as well as a number of related species, in cooperative research with Dr. C. Wayne Berisford, University of Georgia. The *R. frustrana* pheromone lived up to its name and was very *frustrating*. Although the major pheromone component was easily identified, it had no attractant activity to male moths in the field. After several years of research, we identified a minor component from the female pheromone glands that gave good attractant activity when present at ca. a 3:97 ratio to the major component (Hill et al. 1981). The pheromone traps then were used to monitor moth flights of this species as a means of timing spray applications for control (Gargerillo et al. 1985; Malinoski & Paine 1988). Although this species is only an occasional urban problem, an IPM approach utilizing pheromone traps provides an excellent method for timing the minimum number of insecticide applications required when control becomes necessary.

Clearwing Borers

Clearwing borers are common pests of woody plants. The larvae tunnel in living wood and destroy vascular tissues, as well as providing entry points for disease pathogens. Trees in the urban landscape are especially prone to borer attack, especially if they are under environmental stress due to moisture deficiency or sunscald. Some of the clearwing borers affecting the urban environment include the following (Potter & Timmons 1983): The peachtree borer, *Synanthedon exitiosa* (Say), and lesser peachtree borer, *Synanthedon pictipes* (Grote and Robinson), are important orchard pests, but also pests of peach, flowering cherry, and other *Prunus* species in the landscape; the lilac borer, *Podosesia syringae* (Harris), which is a pest of lilac, privet and ash; the dogwood borer, *Synanthedon scitula* (Harris), which attacks flowering dogwood, pecan, hickory, apple, cherry, and other alternative hosts; the oak borer, *Parathrene simulans* (Grote), which is a pest of oaks - particularly red oak and pin oaks; the ash borer, *Podosesia aureocincta* Purrington and Nielson, causes damage to ash in landscape and nursery trees; and the rhododendron borer, *Synanthedon rhododendri*, (Beut.).

Identification of the pheromone components for the peachtree borer and lesser peachtree borer (Tumlinson et al. 1974) provided chemicals that proved to be common pheromone components in various ratios for a whole array of clearwing species, including all those mentioned above (Nielsen et al. 1975). Commercial attractant lures were developed for these clearwing species and used in monitoring traps to accurately document species distribution and flight periods, and to time insecticide applications more effectively (Meyer et al. 1988; Neal 1981; Neal & Eichlin 1983; Nielsen 1978; Warner & Hay 1985). For example, male moth captures in pheromone monitoring traps indicate that mating and egg laying has begun for that specific species and so a spray applied 10-14 days later would coincide with the beginning of the larval hatching period.

In a study by Booth and Becker (personal comm.) in 1986 in Baltimore, it was found that the use of IPM tactics could drastically lower the amount of insecticide used on urban properties. Dursban provides excellent control for clearwing borers and has generally been applied as a preventative spray for clearwing borers. In this study it was found that on the 10 urban properties involved, a total of 4.1 kg of Dursban was used per year, with about 90% of it for control of clearwing borers. After initiation of the IPM program, only 0.1 kg of Dursban was needed to provide effective control. Thus, the overall IPM program for all insecticides used on these properties greatly reduced the total amount of insecticide used and showed the importance of this approach in urban environments.

Bagworm

Bald cypress are an excellent urban tree in the South and are widely used in Charlotte, NC. They are very tolerant of soil and air pollution problems, but are plagued by two arthropods - bagworms, *Thyridopteryx ephemeraeformis* (Haworth), and spider mites. In 1984 the city arborist, Don McSween, contacted Don Booth for assistance because for years the city had to spray 3-4 times per year. The bagworms were the main culprit because sprays with Sevin and other insecticides for bagworm stimulated mite outbreaks. Dr. Booth knew that the sex pheromone for the bagworm had been identified (Bierl-Leonhardt et al. 1983) and that the isolated setting of the trees within the city might provide an ideal situation to attempt mass trapping for control of this pest. On September 15, 1984, a total of 19 bagworm traps were hung in two different sites (total of 33 trees). The trees in these plots had received two applications of BT, which achieved 84% control. In the next two months, a total of 1,291 bagworm males were captured in the pheromone traps. In 1985 no live bagworms could be found on the trees and the city has not had to spray trees in these plots for bagworm since that time. It is a great success story for utilizing the pheromone mass trapping technique with small isolated populations. Other research (Klun et al. 1986) has shown that there is potential for using the bagworm pheromone for protecting individual trees by releasing the chemical from sources for mating disruption.

FIRE ANTS

The fire ant, *Solenopsis invicta* Buren, not only is a pest of crops, ranging from citrus to potatoes, but also is a pest of humans because of its aggressive behavior and potent venom. It was accidently imported into the U. S. in the 1930's and quickly spread through the southern states. Recently it has been reported in California, Arizona and Oklahoma and could spread through the western seaboard. Baits were developed for fire ant control because they offer large scale treatment possibilities and much less insecticide. Traditional baits have included a) a solvent for the active ingredient, usually soybean oil since it also acts as a phagostimulant that induces the fire ant to ingest the material, b) a carrier, such as a pelletized corn cob product, which is an inert material with a high capacity to absorb the soybean oil/toxicant, and c) an active ingredient that has delayed toxicity and insecticidal activity over a wide concentration range.

Dr. Robert Vander Meer (USDA, Insects Affecting Man and Animals Research Laboratory, Gainesville, FL) has been working on the baits and is attempting to improve their effectiveness and specificity to fire ants by using species-specific attractant pheromones in the baits. Blends of compounds for two different attractant pheromones have been identified. One pheromone produced by the queen attracts workers and induces them to aggregate and bring brood around the queen (Rocca et al. 1983). A bioassay system was established that tested the various components for attractancy activity (Vander Meer et al. 1988). Although the whole blend was the most active, a single component at a higher concentration was found to be almost as active and would represent a more economical alternative in species-specific baits. The second pheromone to be studied is a worker recruitment pheromone that is produced in the Dufour's gland and is released through the sting. One of the behaviors associated with this pheromone is attraction and so it also has potential to be used in a bait. Several components of this pheromone have been identified (Vander Meer et al. 1988) and an attraction bioassay established to evaluate their activity. Some of the components have proved to be quite active and have increased the activity of baits in tests conducted to date. Dr. Vander Meer states that there are still obstacles to overcome, but he believes that they are close to enhancing the effectiveness of a fire ant bait by using species-specific pheromones.

WASPS

Southern Yellowjacket

The southern yellowjacket, *Vespula squamosa* (Drury), is found throughout the eastern United States and south into Guatemala. It is a pest to humans because of its abundance, large colony size, and aggressiveness. Drs. Peter Landolt and Robert Heath (USDA, Insect Attractants Lab., Gainesville, FL) have documented that this species utilizes a chemically mediated alarm behavior (Landolt & Heath 1987) to orient to the source and to focus attacks. They identified the compound as N-3-methylbutylacetamide (Heath & Landolt 1988) by utilizing baited versus unbaited traps in the field. This chemical is very potent in attracting the wasps to traps in a very short time. For example, a load rate of only 250 ng on a trap can attract over 100 wasps in two minutes when placed at a distance of 2 m from a yellowjacket colony entrance, thus making it difficult to deploy the trap and escape before the onslaught of wasps. The extreme potency of this material limits its commercial use at present, but perhaps its attractancy can be harnassed for useful purposes in the future.

Paper Wasp

A number of paper wasp species in the genus *Polistes* are pests because they aggregate and swarm near the top of tall structures, such as the space shuttle launch, fire towers, tourist lookout towers, and even the bell tower at the University of Florida (Landolt, personal comm.). Female wasps aggregate and form a hibernacula site, around which the males form loose swarms and mark perches with scents from large mandibular and sternal glands. Research (Reed & Landolt 1990) on one species, *Polistes exclamans* Viereck, has shown that there is upwind attraction in flight tunnel bioassays of males to female odors and of females to male odors. Dr. Landolt believes that the identification of some of these attractants could provide a method for trapping wasps that are aggregating up on the towers.

BOXELDER BUG

Boxelder bugs, *Boisea trivittatus* (Say), are annoying household pests when they invade the home during the early spring and fall months. They do not feed on food or clothing, but create problems by soiling curtains and walls with their excrement. They usually feed on the flowers, leaves and seed pods of female or seed-bearing boxelder trees, but also can be seen on maple, ash and even on fruits such as grapes, apples, peaches, plums and pistachio. The boxelder bugs belong to a group of insects called the scentless plant bugs. This term is somewhat of a misnomer since these bugs are remarkable natural product chemists and secrete material from dorsal abdominal scent glands, and a ventral abdominal gland associated with the genitalia. Dr. Jeffrey Aldrich (USDA, Insect Hormone Lab., Beltsville, MD) is investigating the array of chemicals released by this complex of rhopalid species, including the boxelder bug, and already has identified 21 volatile compounds (Aldrich et al. 1990). Secretions from certain glands were species specific, but with intraspecific uniformity, which suggests that some of the compounds may act as pheromones for species recognition and aggregation. Further investigation of the biological roles for these secretions could lead to species-specific traps to be used for monitoring and control of the pest species.

STORED PRODUCT PESTS

Pheromones have been identified for the major stored product pests and have been used throughout the world for monitoring and control. An excellent review of their use was presented by Dr. Wendell Burkholder at the National Meeting of Urban Entomology in 1988 (Burkholder 1988). It is not the intent here to review the tremendous growth in the use of pheromones in this area, but a few recent developments will be discussed. A number of companies are very active in this area, and one that provides a wealth of information on pheromones of stored products is Insects Limited, Inc. in their newsletter entitled "Fumigants and Pheromones". The company was founded in 1981 by David Mueller and it specializes in the distribution and implementation of pheromone trapping programs primarily to commercial companies working with stored products. Mueller recently conducted a survey of pheromone traps/lures distributed by his company for stored product insects in 1988-1989. He found that 49% were distributed for the cigarette beetle, *Lasioderma serricorne* (F.), 20% for the Indianmeal moth, *Plodia interpunctella* (Hubner), 14% for the warehouse beetle/Khapra beetle, *Trogoderma* spp., 5% for red & confused flour beetles, *Tribolium castaneum* (Herbst) and *T. confusum* Jacquelin du Val, and the rest for lesser grain borer *Rhyzopertha dominica* (F.), sawtoothed grain beetle, *Oryzaephilus* spp., drugstore beetle, *Stegobium paniceum* (L.), and the Angoumois grain moth, *Sitotroga cerealella* (Olivier).

In spite of the wide-spread use of pheromones in stored products, the market has not grown to its potential. Some of the hesitancy to use these environmentally safe devices as an early warning system to detect insect infestations stems from a fear that FDA inspectors will use trap catches as a means of condemning warehouse facilities. According to Dr. Vera Krischik of the Federal Grain Inspection Service "Presently, FDA inspectors do not have an established policy indicating how to treat insects found in insect traps. Consequently, inspections can be subjective and FDA field offices can have different policies on how to treat insects found in traps and whether to rate the insects as filth. Insects, in general, are considered as filth by FDA standards and the presence of insects can be used towards a poor review of a facility. As a result of FDA policy that insects are considered as filth regardless of their occurrence in traps or in the structure itself, warehouse owners are not using insect traps in fear that their presence in a trap will be used against the facility in a condition exam. The concern that insects found in traps can be used against a facility is slowing down the implementation of insect traps in warehouse pest management programs".

The above concerns about the use of insect traps resulted in action by David Galliart, chairman of the Grain Insect Interagency Task Force and Deputy Administrator of the Federal Grain Inspection Service, by way of writing Fred Shank, Director of the Center for Food Safety and Applied Nutrition of the FDA. The good news is that Dr. Shank was very positive in responding to this problem and has taken action to establish a consistent policy in the use of these traps. He says in a letter of January, 1990 that "we do not consider the presence of insects in an insect population monitoring device as evidence that food has been prepared, packed or held under insanitary conditions or that the food itself is filthy. The presence of these devices would be considered as part of an investigation but not as evidence. The presence of insects in these devices would be a good opportunity for us and firm's management to discuss sanitation in general and to determine if there is an infestation within range of the device. If an insect infestation of significant magnitude is found, then we could initiate regulatory action if necessary. However, any such action would be based on the presence of insects in or near the food itself not on the insects in a monitoring device. We believe that the proper use of insect population monitoring devices by a firm's management is an excellent adjunct to preventative sanitation procedures. A copy of this letter will be provided to our field office managers for their guidance concerning insect monitoring devices."

It is very encouraging to have a positive response from the FDA and it is hoped that they will continue to pave the way for an increased use of pheromones in the monitoring and control of stored product pests.

COCKROACHES

Surveys of pest control operators, residents, and entomologists indicate that cockroaches are of greatest concern, with the most important being the German cockroach, *Blattella germanica* (L.). A recent review provides an excellent discussion of various aspects of IPM programs for cockroaches (Schal & Hamilton 1990). It is obvious that there is a great need for some type of attractant to increase the effective range of baits for the German cockroach. To date, the only cockroach pheromones with attractant activity are Periplanone A and B identified from the American cockroach, *Periplaneta americana* (L.). These components also are cross attractive to related species, such as *P. americana* and *P. australasiae*, as well as *Blatta orientalis*. Unfortunately, no aggregation or attractant chemical has been found for the German cockroach, although a number of contact pheromones have been identified.

Although the brown-banded cockroach, *Supella longipalpa* (F.), is not as important a pest as the German cockroach, it does possess of number of characteristics that make it more suitable for identifying an attractant pheromone. The female releases a volatile sex pheromone during scotophase and the male cockroaches are attracted to the females over distance. With these advantages present, Dr. Schal and I initiated a cooperative project to identify this attractant pheromone and to determine if it could be used to increase the effectiveness of monitoring traps. Briefly, we have determined the location of the female sex pheromone gland, assessed various methods of harvesting these glands or airborne material from these glands, established a protocol utilizing the electroantennogram assay technique to purify the material to a single compound, and have carried out a number of chemical and instrumental analyses on the compound in pursuit of its chemical structure. An empirical formula is in hand, but a final structural formula still must await the addition of further data. If this project succeeds in the production of an attractant chemical for use in traps, the next logical step would be to apply our cooperative resources to the more important German cockroach challenge.

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PHARAOH'S ANTS - AN OVERVIEW

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The Pharaoh's ant, Monomorium pharaonis (L.), is probably the most widely distributed of all ant pests. The type-specimen described by Linnaeus (1758) was from Egypt, and it is likely that the species originated in the North African region. However, during the last 200 years the species has spread (largely as a result of increasing international trade) and is now truly cosmopolitan. The ant is widespread in Europe and has been recorded in the United States, Canada, Russia, South America, Australia, Japan, and is probably widespread throughout the tropical regions of the world. In non-tropical climates, the species is dependent on artificial heating and infestations are invariably associated with human habitation. In the UK infestations are most often found in hospitals, bakeries, factories, offices and large domestic apartment blocks. This ant was first recorded in the UK in 1828 (in London), and is now distributed throughout the country. About 12% of all National Health Service hospitals in England and Wales are infested, and infestations are more prevalent in major cities - i.e. areas of high human population (Edwards and Baker, 1981).

Because worker ants are known to carry a wide variety of bacterial pathogens (including Salmonella, Pseudomonas, Klebsiella and Clostridium spp., Beatson, 1972) infestations in domestic or institutional premises are a potential public health hazard. Moreover, although many other urban insect pests (e.g. cockroaches) also carry pathogens, pharaoh's ants have a number of behavioural traits that suggest that infestations may represent a particularly serious risk to human health (Short, 1988). For example, the small size of the workers (2mm long) means that they often remain unnoticed, and are able to pass through the smallest gaps to invade equipment and foodstuffs. Workers can also readily chew their way into sealed packages and chambers, and have been found in sterile supplies, in sets for giving intravenous fluid, inside premature baby incubators and even under wound dressings. In addition, workers seem to seek out sources of moisture, and are frequently found feeding at sluices, drains, toilets and other similar areas likely to harbour disease organisms. When such sources of food and water are located by foraging workers, many others will be recruited to feed at the same site, thus increasing the chance of contamination. Moreover, when foraging workers become contaminated with potential passed and return to the nest, it is likely that these pathogens will be pleased to nest-mates, thus increasing the number of individual insects capable of transmitting the pathogen. Lastly, the environmental conditions existing in the nest (warmth and high humidity) coupled with the presence of stored food reserves, could promote the survival and increase of pathogens like gram-negative bacteria.

Colonies of the pharaoh's ant are polydomic (i.e. comprised of several nests), and there is no aggression between nests. Indeed, these ants may move to and fro between several nests as environmental conditions change. The nests occupy any suitable crevice, and are usually located deep within foundations, wall cavities and underground service ducting. The nests contain the brood stages (eggs, larvae and pupae), numerous workers and several queens. In laboratory colonies, the number of queens varies from a few individuals to several hundreds. Queens usually remain inside the nest and are soley responsible for egg laying. Fertile queens live for about one year, and lay upto 35 eggs per day. In the presence of fertile queens, only workers will be produced from these eggs, and the developmental period (egg to adult) at 27°C is about 36 days (Peacock et al., 1950). The average longevity of adult workers is about 10 weeks.

In most ant species, new nests are founded by single fertilized queens following a "nuptial flight". In pharaoh's ants there is no nuptial flight (although both males and queens are winged, they do not fly), and mating takes place in or near the nest. Fertilized queens shed their wings, and usually return to the nest in which they were reared. For this reason, colony foundation in M. pharaonis occurs by "budding" or sociotomy. Thus, new nests are founded by small groups of workers carrying brood stages to a new nest site. Although queens often accompany these migrant groups, their presence is not necessary for the successful establishment of a new nest since, in the absence of queens, workers will rear new queens (and males) from the transported brood. The minimum numbers of ants able to establish viable new nests appears to be about 100 workers and a similar number of brood stages. Often, these migrating groups will occupy a temporary nesting site while searching for a more permanent abode. It seems that the (inadvertant) transportation of such temporary nests by humans is the main method by which infestations are carried to new areas or premises.

In pharaoh's ants, males are produced from unfertilised (haploid) eggs, and the two female castes (queens and workers) from fertilised eggs (Smith and Peacock, 1957). Under normal circumstances, the presence of fertile queens in the nest inhibits the production of males and queens. Workers are signalled of the presence of fertile queens by the large numbers of eggs present in the colony (Edwards, 1987). In response to this signal, workers cannibalize any male or queen larvae soon after these hatch from the eggs. Workers recognise these sexual larvae by the absence of hairs - worker larvae are covered with short bifurcated setae (Edwards, unpublished results). As the queens age, their egg production decreases and the reduction in the numbers of eggs in the colony stimulates the workers to rear a new generation of males and queens. Thus, it appears that caste is determined in the egg (perhaps genetically) and that the appearance of a new sexual generation is dependant on the behaviour of workers towards developing larvae.

Pharaoh's ants are ominivorous and feed on a wide variety of food materials. Foraging workers leave the nest to scout for food and water. Once a new food source has been located, the worker returns to the nest laying a chemical trail on the ground for others to follow (Holldobler, 1973). These trails may be many metres long, and are constantly re-inforced as more workers travel to and from the food source. The main component of this trail pheromone (faranal) is produced in the Dufour's gland (Ritter et al., 1977) and deposited through the sting. Because the sting has been adopted for this purpose, pharaoh's ants (unlike their close relatives the fire ants) do not sting.

Because pharaoh's ants are readily attracted to new food sources, baiting, with baits containing a variety of active ingredients, has been the main method of treatment. There has been considerable speculation on the subject of the most attractive bait materials. Traditionally, liver (either raw or dried) has been the food material most often used in baits. However, the predominance of liver appears to derive soley from an early anecdotal report of its use (Belavoye, 1889). Other workers have reported good results with mint apple jelly (Granovsky and Howell, 1983) or with peanut butter and honey (Edwards and Abraham 1990). However, recent studies have revealed that pharaoh's ants appear to become satiated when offered the same bait over a period of time and may change their initial preference and select alternative foods (Edwards and Abraham, 1990). Thus, no single bait material (even if it is a mixture of several food types) will remain attractive to foraging workers over a long period of time, and permanent bait stations may become less attractive the longer they remain in place.

Pharaoh's ants have always been difficult to control, and the spectrum of chemicals employed against this species ranges from inorganic poisons (e.g. thalium sulphate, sodium fluoride and boric acid), through a variety of organic insecticides (including dieldrin and chlordecone) to more modern chemicals like methoprene and hydramethylnon).

Current control methods are based either on the use of residual insecticides (usually applied as a spray) or on the use of baits slow-acting poisons or other agents. Spray treatments are usually aimed at achieving rapid reduction in worker numbers, but although such treatments often achieve spectacular initial results, they seldom result in the complete eradication of the infestation. There are several reasons for this. For example, such treatments do not generally reach the nest and therefore are not effective against queens. In addition, the nest contains food reserves and colonies may survive for considerable periods without the need to forage in areas treated with insecticides. Moreover, insecticide treatments, particularly if these are carried out on a limited basis, may induce the migration of nests to other areas where insecticides are absent or where physical conditions make their application impossible. However, residual spray treatments can be of benefit in areas where rapid elimination of the worker population is essential (e.g. operating theatres).

In general, baits are more effective than spray treatments in eradicating widespread established infestations of pharaoh's ants, and they have a number of advantages over the latter method. First, the placing of baits in an infested premises is often less disruptive to those working or living there than is a treatment involving the application of insecticides. Second, baiting ensures that the active ingredient will be transported by workers back to the nest, and the treatment will be effective against the egg-laying queens. A variety of active ingredients have been incorporated into baits, including boric acid (Newton, 1980), bacterial pathogens (Vankova et al., 1975) chemosterilants (Berndt et al., 1972) and the insect juvenile hormone analogue methoprene (Edwards, 1975). These materials have been shown to be effective, and no doubt there are other active ingredients that can be effectively incorporated into attractive baits. However, at least as important as the choice of active ingredient is the way in which a baiting treatment is carried out. First, it is important to establish the identity of the infesting species. This is because many house-infesting species are superficially similar to Monomorium pharaonis, but not all are susceptible to baiting. Second, it is equally important that a thorough survey of the infested premises be undertaken prior to treatment to determine the full extent of the infestation -otherwise nests present in untreated areas will simply re-colonise the treated areas. For similar reasons, treatment must be thorough if it is to be effective, and all areas including ducting and roof spaces must be treated. Finally, following treatment, some form of monitoring should be carried out to ensure that no nests have escaped treatment. Small residual populations will give rise to entensive infestation if they are not picked up by post treatment monitoring.

In summary, pharaoh's ant is a serious potential health hazard in domestic and institutional premises. However, using baits containing compounds with low vertebrate toxicity and insect-specific action (e.g. juvenile hormone analogues), infestations can be successfully eradicated (Edwards and Clark, 1978).

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THE ISSUE OF INSECTICIDE REPELLENCY

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ABSTRACT

Several test procedures have been developed to investigate the repellent activity of compounds including insecticides used for cockroach control and non-insecticides used for insect population management. Among the tests reported are the ground glass cylinder method, the slanting card or slant board method, the harborage choice method, the choice box method, and the arena test. Data on insecticides show that repellent activity can be detected for many compounds. However, when field data and environmental factors are considered there is an indication that the impact of repellency on field efficacy may not be important for most compounds.

Keywords - Insecticide repellency, harborage choice, choice-box, arena test, slant board

The issue of insecticide repellency is complex and, perhaps, evasive. Answering whether or not there is an issue is perhaps the most complex and evasive question of all. This paper will address laboratory methods for measuring repellency and in so doing give a historical perspective of the repellency question. It will review laboratory data and companion field data where available, and conclude with a discussion of environmental considerations that impact on repellency.

REPELLENCY TESTING PROCEDURES

The history of repellency testing can be traced in the literature back to the early fifties when Goodhue & Tissol (1952) published a procedure to determine the repellent action of chemicals to Periplaneta americana (L.), the American cockroach. It was also during this period that U.S. government researchers in conjunction with commercial suppliers began synthesizing and testing candidate compounds (Bodenstein & Fales 1976). These early origins are important because repellent activity was not considered a detriment. In fact, the goal of the earlier research was to identify compounds that could be used to keep cockroaches from entering targeted areas -- to provide a barrier, not necessarily to serve as an insecticide.

Some of the test procedures found in the literature are: (1) the ground-glass cylinder method and (2) slanting card or slant board method both by Goodhue (1960), (3) the harborage choice method used by Goodhue & Tissol (1952) and Burden & Eastin (1960), (4) the choice-box method of Ebeling et al. (1966) and most recently, (5) the arena repellency test by Zungoli et al. (1988).

The ground glass cylinder method (Goodhue, 1960) used an apparatus made from three 4 x 4 in. glass cylinders with U-shaped openings at the bottom to allow free passage of the cockroaches between cylinders. After a period of habituation for the cockroaches, treated filter paper was slipped underneath the two outer cylinders, while the center cylinder held untreated paper. Different surfaces could be substituted for the filter paper. All data were collected within two days after exposure to treated surfaces. This method was used primarily for tests against P. americana and Blatta orientalis L., the Oriental cockroach. The procedure worked only very poorly for Blattella germanica (L.), the German cockroach.

The slanting card or slant board method also by Goodhue (1960) was developed to test repellent compounds against B. germanica. In this procedure a plastic box, 8 x 12 x 8 in. (w x l x h), was used to rear German cockroaches. When the colony numbers were large, a maximum of 2000 individuals of mixed age, the test was conducted. At this time 3 x 5 in. file cards, sections of beer cartons, fiber board, sheet metal, glass or other surfaces were treated and placed inside the plastic box along with an untreated panel. All panels were placed at a 25° angle. Data were collected at 1, 2, 4 and 6 hours.

The harborage choice method was also used to test repellent and insecticidal compounds against B. germanica (Burden & Eastin 1960, Burden 1975). The insides of either half or one pint cartons were treated. A three-quarter inch hole was made in the carton to allow free access. One treated carton was placed in an enamel pan where food and water were available. Ten male and ten female cockroaches were placed in the pan and data were collected at 1, 3 and 7 days then weekly thereafter.

The choice-box test by Ebeling et al. (1966) is the best known of the repellency test procedures. Its development marks the point at which interest was turning from "good" repellency or those compounds that were intended to provide repellent activity rather than insecticidal activity, toward "bad" repellency or those compounds intended to provide insecticidal activity rather than repellent activity. The choice-box is constructed of 1/4 in. plywood. It is 1 ft. square and 4 in. high with a partition dividing the box into two equal compartments. A 3/8 in. hole was drilled near the top of the partition wall and when covered it was the only means of entry from one compartment to another. The compartment into which cockroaches were placed was covered with 1/8 in. plexiglass with a 1 in. hole through which the test insects were dropped into the box. The other compartment was covered with plexiglass and a piece of masonite to keep out light. Insecticides were applied to the dark halves of the boxes and test insects along with food and water were placed in the lighted half. Cockroaches normally move from the lighted half to the darkened half of a box, unless the insecticide is repellent. The choice box test can be used to study repellency to species of Blattella, Blatta and Periplaneta.

The arena test was developed to evaluate relative repellency of several compounds within a single test apparatus allowing for direct comparison of one compound against another (Zungoli et al. 1988). The test was designed to investigate insecticide repellency to German cockroaches. Treatments of different compounds were applied to 1 qt. paper cartons using an air brush sprayer. After treatment, 1 pt. jars baited with cat chow and beer and with inner lip lightly coated with petroleum jelly were placed within the paper cartons so that the rim of the jar was flush with the rim of the carton. These treated harborages were then placed equidistant from each other and the center of the arena. The arena was 1 m in diameter. Cockroaches slowed by refrigeration were then placed in the center of the arena and left in a totally darkened, undisturbed room for 4 h. After 4 h, the number of cockroaches within each harborage and the arena were counted. The test is conducted as a latin square design so the number of replications is equivalent to the number of compounds tested plus a control.

TEST RESULTS

The harborage choice test initially used to test compounds for "good" repellency was later used to test compounds for "bad" repellency. Burden (1975) reported on repellent and non-repellant compounds. In general he reported organophosphates to be non-repellent and pyrethrins, pyrethroids and carbamates to be repellent. Although few, if any, cockroaches were found in cartons treated with the later compounds it should be noted that mortality was high for propoxur. This indicated that cockroaches had entered the treated harborages at some time during the test.

Early work with choice box testing compared boric acid dusts to diazinon, Borax, Drione, sodium fluoride and propoxur. In all tests, boric acid was non-repellent, while other compounds, to varying degrees, were repellent (Ebeling et al 1967, 1968).

In a study by Rust & Reierson (1978) the combined effects of the biological activity and the repellency of each toxicant was considered and a potential for effectiveness in the field was calculated. The number of dead cockroaches at the end of the test indicated the maximum degree of mortality produced by the toxicant. The number of cockroaches alive in the untreated light compartment indicated the degree of repellency of the treatment applied to the dark side. Their results for potential effectiveness fall into three groups. Chlorpyrifos and diazinon had the greatest potential giving complete mortality by the end of the study. Bendiocarb, carbaryl, fenitrothion and propoxur gave positive values for potential effectiveness, but some cockroaches were alive at the end of the study. While propoxur and silica gel resulted in negative potential effectiveness values, due to incomplete treatments, with increased populations living in less-preferred harborages. In the field test that followed, chlorpyrifos gave 97% control at four weeks, followed by propoxur at 88%, diazinon at 75% and variable results with bendiocarb ranging from 0 - 84% reduction. It is noteworthy that while propoxur gave 88% at four weeks after treatment, the population was significantly increasing at eight weeks. Poor and variable results with bendiocarb and propoxur were determined to be due to resistance, not repellency. In general, these results are similar to those of Burden (1975). Organophosphates were less repellent than carbamates.

In another study by Reierson et al. (1979) the same pattern of potential effectiveness resulted with the organophosphates, chlorpyrifos and diazinon with the highest values, followed by the carbamates (bendiocarb, carbaryl and propoxur), followed by pyrethrins and the pyrethroid, fenvalerate.

In arena tests with adult male B. germanica, similar trends were found (Zungoli et al. 1988). Due to the comparative nature of the test there was an overlap of repellency in toxicants with no significant differences between chlorpyrifos, diazinon, propoxur, and propetamphos and no significant difference between propetamphos and fenvalerate. The repellent activity of these same toxicants against early and late instar nymphs was also compared (Zungoli & Benson, unpublished data). The results indicate that there is a differential response to a toxicant based on insect age. Diazinon is not significantly different than fenvalerate in this study, nor was chlorpyrifos significantly different than propoxur. The latter are two compounds found to be on opposite sides of the repellency scale in all of the studies previously discussed. One of the few studies found in the literature that reports chlorpyrifos to be a repellent insecticide is by Rauscher et al. (1985) in which the effects of food, water and light on the distribution of B. germanica in choice boxes was investigated. They report that the presence of chlorpyrifos strongly influenced distribution and was repellent under all conditions tested (Rauscher et al. 1985). Their study and most others were conducted using adult male B. germanica, not two age classes of nymphs as in the arena test study.

ENVIRONMENTAL CONSIDERATIONS

Would there be differential trap catches based on age class in treated and untreated areas in a field study? What do all of these laboratory data imply for evaluating field efficacy? How important is repellency in field efficacy? In the Rust & Reierson (1978) study, results in the laboratory did not directly compare to results in the field due to the confounding factor of resistance. Unfortunately, there are few other comparative laboratory and field studies reported in the literature. What we do have is more laboratory data, but unlike the repellency studies these data would indicate that field environment is an important factor in whether or not repellency impacts on control.

How does environment affect repellency? Early studies by Ebeling & Reierson (1970) on the effect of population density on exploratory activity and mortality rate of B. germanica in choice boxes may begin to answer this question. In both treated and untreated choice boxes, the rate at which the insects entered the darkened compartments was inversely proportional to density, because of increasingly greater exploratory activity with decreasing number of insects per box. However, mortality rate was directly proportional to population density. They explain that as the number of cockroaches per choice box increased, competition for preferred insecticide-free niches also increased. Thus cockroaches were less able to modify their behavior so as to avoid repeated contact with insecticide (Ebeling and Reierson 1970). It is also possible that with increasing density, insects that have contacted treated surfaces will in turn contaminate their cohorts and have the effect of increasing mortality.

Rust & Reierson (1977a, 1977b) investigated the potential of using pheromone extract to reduce repellency of insecticides to B. germanica in choice studies. They report that the efficacy of the toxicants was generally inversely related to repellency. However, when toxicants were combined with aggregation pheromone for control of young nymphs and adult males, the impact of repellency was reduced and the period of time cockroaches contacted each toxicant was increased. This resulted in significantly higher rates of mortality when aggregation pheromone was added to a toxicant than for any toxicant alone. In field control tests results were comparable to choice box studies. The addition of pheromone extract significantly increased control of all toxicants used in the study compared to toxicants applied alone. If pheromone extract, when added to a toxicant, can increase control, would preferred harborages in field settings serve the same purpose? If toxicants are sprayed into harborages that are previously contaminated with aggregation pheromone would a "repellent" toxicant induce activity or would the presence of the aggregation pheromone override the impact of repellency? If repellency did cause an avoidance response toward a treated surface would that response be delayed long enough to allow for adequate exposure to cause high mortality?

In a recent publication by Barcay et al. (1990) the influence of insecticide treatment on B. germanica movement and dispersal within apartments was examined in a mark-recapture study conducted in multi-family housing. They selected four insecticides to represent the typical flushing, repellent and residual qualities of insecticides used for cockroach control. They reported no significant changes in cockroach distribution and rates of movement within apartments decreased due to insecticide induced mortality. They stated that any initial increased movement activity of cockroaches surviving insecticide applications would be negated by mortality induced by insecticides or knockdown, with the net effect being reduced numbers of individuals moving between areas. Further, in a study where populations were treated with sub-lethal doses of pyrethrins and resmethrin, these researchers reported that cockroaches settled to their original distribution within 24 hours after treatment (Barcay et al. 1990). These data indicate that toxicants determined as being repellent in laboratory studies may not be repellent beyond a limited period of time in the field. A study by Ross & Bret (1986) aboard an inactive ship reports that most cockroaches return to their original harborage locations within 1 to 2 weeks and only small groups remain in previously uninhabited harborages. The point made by Barcay et al. (1990) is that these studies and other emphasize the need for thorough application of insecticides to all cockroach harborage.

IMPACT OF REPELLENCY ON CONTROL

What affect does repellency have on control? If laboratory generated data is used the answer would be that it has a great affect. However, Schneider and Bennett (1985) conducted a comparative study of several methods for determining the repellency of blatticides and concluded that laboratory repellency tests have limited usefulness in predicting the influence of repellency under variable field conditions. In arena studies where relative data are available there is no significant difference between compounds that have previously been categorized as non-repellent and those that have been categorized as being repellent (Zungoli et al. 1988). These studies indicate that repellency may not have a major impact on field efficacy. The studies of Ebeling and Reierson (1970) and Rust and Reierson (1977a, 1977b) suggest that variable conditions such as population size and prior contamination of harborages with aggregation pheromone reduces the impact of repellency.

So, what is the answer to the question of repellency - is it an issue or not? Certainly more field research is needed to conclusively make that determination, and laboratory testing is helpful in identifying compounds that exhibit excessive repellent activity. However, there is an indication, that repellency of most toxicants currently available should have a variable, but minimal impact on control and that proper placement of insecticides in harborages can reduce the impact of repellency in the field.

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Problems Associated With Evaluating Cockroach Control Chemicals

Laboratory Test Methods

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There are **two general objectives of laboratory testing.** These are simply to compare samples relative to a specific performance attribute in a bioassay conducted within a controlled laboratory test setting, or to conduct a bioassay which will reliably predict how the product or formulation will perform in the field. This latter objective is sometimes simply stated as correlation of laboratory and field results. There are many types of cockroach control insecticide product forms which seek to provide insecticidal activity in different ways or over different time frames. However, to date, the most commonly used laboratory methods for testing residual insecticides (e.g., sprays and dusts) and baits for cockroach control are inadequate to reliably predict the level and duration of product performance in the field (e.g., as measured in field tests so commonly conducted within infested apartments, see discussion of G.W. Bennett below).

Direct Spray Knockdown Tests

Perhaps the simplest and most easily tested insecticidal activity for cockroach insecticides is **direct spray knockdown** and kill. This performance dimension is important primarily to consumer products marketers, who use rather straightforward and well accepted testing methods to measure the time required to knockdown cockroaches upon direct spray[1]. The basic Chemical Specialties Manufacturer's Association (CSMA) direct spray knockdown test method involves directly spraying groups of caged adult male cockroaches from a distance of 18 inches, and assessing knockdown at appropriate intervals (e.g., 30 seconds for German cockroaches, 60 seconds for American cockroaches) through 5 or 10 minutes.post-treatment. Final mortality counts are typically made at 24hrs post-treatment. Knockdown data are summarized and typically presented graphically as curves which relate the mean percentage knockdown at the various post-treatment sampling intervals for each sample. Knockdown times for 50% (KD_{50}) or other proportions of the test populations (e.g., KD_{70} or KD_{90}) can be determined. Comparative statistical tests on the mean performance at each post-treatment interval (i.e., comparing treatment means within each interval) can also be used to identify significant differences in insecticidal activity.

Comparative use of laboratory (typically insecticide-susceptible) and field strains (resistant to various insecticides?) of test insects may be appropriate. Agreement by urban entomologists on a limited number of reference lab and field strains of German cockroaches for this purpose (and for use in residual test methods, discussed below) would be desirable. These strains could then be maintained by recognized laboratories, which could act as sources for other researchers.

Residual Tests

Conventional test methods for residual insecticide performance against cockroaches can be separated into **two categories - panel tests and arena tests.**

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[1]Ref./ Anon. 1967. CSMA cockroach aerosol test method. Soap & Chem. Spec. [Blue Book Issue] 43(4A): 209-210.

Panel tests involve application of insecticide treatments to small panels (e.g., 6 inches square) with measured amounts of insecticide (spray or dust formulations) and bioassay of these panels at weekly (or other) intervals until insecticidal activity falls below some acceptable level (e.g., 70% mortality). Therefore, results of these panel tests are most commonly reported as "the number of weeks for which 70% (or whatever desired level) of mortality is achieved."

Exposure of insects in panel testing can either be forced (i.e., greased ring on panel to contain insects) or unforced (i.e., ring is not greased and has a screen over its top). The duration of exposure, which is commonly set at 1, 4 or 24hrs., is another test variable. The type of panel used is another important variable, and many different types can be used to assess residual performance on relevant household surfaces.

Besides allowing simple determination of the presence or absence of residual insecticide performance, panel testing allows convenient and useful comparison of residual performance between samples (on different surfaces). However, this method has problems of poor correlation to field test results[2]. Several reasons for this can be readily identified, including repellency of insecticide deposits (so exposure times in panel testing may be unrealistic), insecticide resistance of field cockroach strains (so different strains should be used in testing), surfaces in the field are frequently coated with grease or dust (so lab test panels should perhaps be similarly "conditioned" before and/or after treatment), and other environmental conditions in the field may be unfavorable for insecticide effectiveness or persistence (so laboratory conditions, typically set at 80°F and 50% RH, may be unrepresentative).

Another practical disadvantage of standard residual panel testing is simply that several to many weeks may be required for a group of panels, treated with various insecticide formulations, to complete the test (i.e., to fail in controlling cockroaches within the test method parameters). This is particularly common with the newer residual pyrethroid insecticides, which can give effective kill for many months in typical panel tests[2]. Clearly, the exposure time can be adjusted to reduce the time required to complete such comparative tests (and make them more efficient in this sense), but this approach means that results from other tests (which involved different exposure times) could not be readily correlated to those from panel tests which involved such a limited exposure time.

An alternative approach to panel testing, which does not seem to have received much attention, could allow more useful comparative information (for different formulations) and shorten the overall test process. Rather than to use a set exposure period and measure the number of weeks required until each sample fails to give 70% mortality, an alternate approach would be to test different exposure periods (for each insecticide and surface combination) in an effort to determine the exposure period required to give a desired, intermediate mortality response (e.g., 50 or 70% mortality). By careful, adequately replicated testing of different exposure times, a dose-response relationship could be characterized and a KT_{50} or KT_{70} value could be determined for each sample. This process could be repeated at weekly (or other) intervals to clearly identify the trends in change of KT response (over a period of residual aging) between samples. Presumably, it would not be necessary to continue this process for more than a few weeks in order to gain the desired information comparing the residuality of candidate formulations.

This comparative KT approach to residual panel testing would provide very useful information as to the minimum exposure time required to provide mortality, and the

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[2]Ref./ Rust, M.K. and D.A. Reierson. 1988. Performance of pyrethroids against German cockroaches. Bull. Soc. Vector Ecol. 13(2): 343-349.

decline of this property over time (i.e., corresponding to the persistence of biological activity). Since formulation chemists would generally prefer to minimize the required exposure time and degradation of this property when they design residual formulations, this KT method would provide a much better basis to compare candidate formulations. Also, since traditional panel testing is poorly correlated to field test results in any case, entomologists should be more interested in knowing how long it takes to give the desired biological activity (i.e., mortality) as a more direct measure of formulation efficiency. This information could then be compared to results from other cockroach repellency tests (e.g., Choice Box tests) to provide more useful characterization of the alternate insecticidal toxicity and behavioral/repellency properties of those formulations under study. The KT approach to panel testing will require a fair amount of developmental research in order to characterize the more commonly used residual insecticides (e.g., residual pyrethroids) and establish the effective treatment rates (active ingredient per unit panel area) and exposure times for each.

Residual Test Methods Involving Cockroach Choice

Residual insecticides are also tested in methods that do not confine cockroaches to treated panels, but present these treated surfaces to the cockroaches in such a way that the insects have a **"choice"** as to whether or not to interact with the insecticide. The most commonly used method of this type is the **Ebeling Choice Box**[3]. However, there have been more recent reports of other **arena test methods** which typically involve larger arenas. These latter arena test methods appear to be favored for testing of IGRs or insecticide baits against mixed cockroach populations. Therefore, by their nature as methods which allow cockroaches to behave in relation to the treatment and (in some cases) use of mixed insect populations, the Choice Box and arena test methods should have greater potential to permit correlation of laboratory and field test results. To date, however, these methods are not sufficiently developed to reliably provide this correlation.

The **Ebeling Choice Box** method was originally designed to test the effectiveness of residual insecticides (primarily dusts), which were being investigated for use in treating (dusting) wall and other voids within infested premises for German cockroach control. This method was carefully conceived to allow simultaneous assessment of both the insecticidal activity and repellency of candidate materials in a way which was very relevant to "normal" cockroach behavior, and in relation to the intended application pattern of the materials under test (when they are used in the field). This method has been appropriately extended to testing other residual insecticide formulations (e.g., residual sprays) which would normally be used to treat harborage areas (e.g., as crack & crevice treatments)[4].

While the method was not originally conceived to be repeated at weekly (or other) intervals in order to evaluate the residual capacity of insecticide formulations, such

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[3]Ref./ Ebeling, W., R.E. Wagner and D.A. Reierson. 1966. Influence of repellency on the efficacy of blatticides. I. Learned modification of behavior of the German cockroach. J. Econ. Entomol. 59: 1374-1388.

[4]Use of the Choice Box to evaluate formulations which are not designed to be used as harborage treatments (e.g., total release aerosol residues, bait stations, residual formulations used as "spot" or "general" treatments (i.e., which are not applied into harborage areas in the field) has been reported. Since the details of the Choice Box design and other aspects of the method rely so strongly on normal German cockroach harboring and foraging behavior in relation to the intended placement of candidate insecticides in the field, interpretation of results from these Choice Box tests should be approached very cautiously.

repeated application can be useful to characterize and compare the residual activity of candidate formulations when the method is otherwise properly applied. However, while the method is useful to generally predict whether candidate formulations will likely give effective cockroach control in the field and why[5] effective control might not be realized (i.e., too repellent, or not sufficiently toxic), results from its repeated use have not been shown to reliably correlate to performance in field testing. At this time, one simply can not take results from repeated application of the Choice Box test method (e.g., on a residual spray formulation) and reliably predict the level and duration of cockroach suppression in the field with reasonable accuracy.

Some advantages of the Choice Box method include its reasonably compact design and versatility in that different types of treated panels (surface types) can be tested. The method is also not too complex for routine implementation by non-professional laboratory technicians. It also has considerable history and some basis of correlation to field performance (as discussed above).

Several researchers have reported results from **arena tests** on cockroach insecticides in recent years[6]. These arenas are usually considerably larger than Ebeling Choice Boxes, at 3-4 foot square (with walls typically ≤1 foot high). These arenas have been used primarily for testing IGR formulations, baits (especially bait stations) and various other product forms, but they have apparently not been much used for evaluating the more conventional residual insecticide formulations (e.g., residual pyrethroids). Mixed GC populations are generally used in these arenas, and treatments are applied after the test population has undergone a suitable acclimation period in the arena. Periodic (e.g., weekly or bi-weekly) total populations are typically conducted, but sub-sampling of the population can yield reliable data under some circumstances (e.g., as per Reid's studies on juvenoids at Purdue, manuscripts in prep.). Harborage arrangement and complexity varies, and positioning of the treatments (e.g., baits or insecticide-treated harborages) will affect results considerably. Some methods allow for GC to choose whether or not to contact treatments (e.g., baits or residual deposits), while other methods provide for some forced contact by placing treated panels under food or water resources. More research toward standardizing this laboratory approach to insecticide testing is required.

Advantages of these arena test methods are that data are obtained on different life stages from a mixed population, which is free running (within the confines of the arena). Data are also obtained in a way very similar to that in field tests, except that total population counts are usually taken (e.g., % reduction/mortality, natality measurements, etc. are possible). Therefore, the potential for useful correlation to field test results is considerable but, as yet, unrealized.

Disadvantages of larger arena testing include the relative expense and bulkiness of the arenas. Many researchers probably do not have available too them the amount of quality laboratory space which would be required to house the many arenas necessary for adequate replication of treatments within an experimental design. Arena test methods need a lot of developmental research work to resolve and standardize the many test parameters, and to establish correlation of results to field situations.

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[5]Ref./ Rust, M.K. and D.A. Reierson. 1978. Comparison of laboratory and field efficacy of insecticides used for German cockroach control. J. Econ. Entomol. 71(4): 704-708.

[6] For example, Koehler, Brenner and Wadleigh at U. Florida/USDA in Gainesville when studying baits and chitin inhibitors, Rust and Reierson in studying baits, Owens at SCJ for studying baits and IGRs, and Bennett and Reid when studying juvenoid IGRs.

Arena tests have also been reported by several research groups which include **video image-analysis or other electronic data gathering enhancements** for very specialized research purposes[7]. These methods appear very useful for measuring activity patterns and/or visitation, which relate well to specific investigation of repellency and attractancy responses (to insecticide baits or residual treatments). To date, there is no apparent trend toward standardization of these methods between research groups. Applicability of this technology to more or less routine insecticide bioassay(s) appears questionable at this time.

Bait Testing

Sweater-box or battery jar arenas are commonly used by many research groups to study bait palatability and mortality (i.e., active vs. inactive?) versus individual cockroaches life stages or mixed populations, but correlation of laboratory results to field performance is poor.

Laboratory testing of baits in **larger arenas**, versus mixed populations,.was discussed above. Pre-treatment conditioning and arrangement of harborages and alternate food sources can substantially alter bait variable performance. These methods require considerable further research and standardization to validate/improve correlation to field results.

Total-Release Products (aerosol or non-aerosol)

This area of laboratory testing can be very complicated and detailed, and is quite specialized within (mostly) the consumer products industry. Insufficient time is available to discuss test methods for these product forms in any detail.

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[7] For example, Brenner/Patterson (USDA-Gainesville), Reierson/Rust (U.Calif.-Riverside) and Barcay/Bennett (Purdue) in studying cockroach baits, and Randall/Brower (SCJ) in studying cockroach repellents (ref., J. Med. Entomol. 23(3): 251-254).

EVALUATING CHEMICALS FOR COCKROACH CONTROL: FIELD EXPERIMENTS

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ABSTRACT The need to develop general guidelines for the biological assessment of chemicals to be used in managing cockroaches is quite evident. If reasonable, scientifically-based guidelines are developed, all interested organizations will benefit from the activity.

Cockroach control, chemical evaluations, field testing, experimental design

INTRODUCTION

Evaluating chemicals for use in managing cockroaches in urban environments involves a myriad of test sites, experimental protocols, data analyses, and methods of reporting results. The biological assessment of a number of different kinds of chemicals (insecticides, insect growth regulators, flushing agents, repellents, etc.) adds to the complexity of the problem. Thus, the formulation of general guidelines relative to the types of tests -- as well as guidelines for the conduct, evaluation, and reporting of such tests -- is needed.

Universities normally become involved in biological assessment activities when initial field testing is needed on a promising chemical. The major objective is to determine the activity of the material. More field tests may be undertaken to determine effective use rates, application strategies, and methods of application if initial tests show promise. This is a key activity in developing supportive performance data, and is most important in generating independent data to support the claims made for a product by the manufacturer and distributors.

TYPES OF TEST SITES

In the urban and industrial complex, there are a large number of situations and locations in which cockroaches can usually be found. German cockroaches are found in large enough numbers in multifamily housing (high rise and low rise) and single family dwellings to conduct efficacy tests. Even within these general types of housing, the situations and conditions are so diverse that it is difficult to generalize without finding exceptions to the rule. However, with general test guidelines, we could certainly improve upon the consistency, completeness, and overall quality of biological assessment of cockroach management chemicals. Not only would these guidelines assist researchers in demonstrating an effect on a pest population in a given use situation, but would also be useful in measuring the reliability and consistency of test data. Guidelines would also help to define the limitations of products, determine that best method or methods of application, and determine the influence of variables such as temperature and sanitation on product performance. At the same time, great care must be exercised to avoid burdensome, unrealistic, impractical standards that will not only stifle research, but more importantly, discourage chemical companies from seeking registrations for their products.

EXPERIMENTAL DESIGN

There are various techniques for controlling pest populations. However, determination of the most effective method by statistical analyses is not always readily apparent. Field experiments are the most realistic, but problems arise due to variables that may cause estimates to be biased. The use of an appropriately designed experiment and proper statistical analyses will minimize any bias.

Evaluation of chemical efficacy in field studies usually involves the comparison of pest population data taken before and after the application of a control method. Raw data are then reduced to percent reductions using the formula:

$$\frac{T_o - T_i}{T_o} \times 100 = \%\ \text{Reduction}$$

where:

T_o = the sample number prior to treatment

T_i = the sample number at time interval i after treatment

This experimental design takes N sample areas (experimental units) and randomly divides them among I groups (methods of control considered for evaluation) with samples taken at K predetermined time intervals. This design is sometimes described as a nested factorial design. The analysis of variance (ANOVA) model can then be developed from this experimental design.

TREATING/APPLICATION

The application of the material to be evaluated is as diverse as the formulation (bait, liquid, dust, aerosol, etc.) and type of chemical (insecticide, insect growth regulator, flushing agent, etc.) being tested. The objective of the experiment will also influence the method of application. All aspects of the way the treatment is established must be carefully considered during the experimental design phase so that meaningful information on the performance of the treatment can be obtained.

True control (untreated) units usually cannot be obtained since residents are not willing to have cockroach populations sampled without a following treatment. Therefore, comparative standards (using materials generally regarded as the best available on the market) are necessary to gain the proper perspective on the performance of an experimental material.

SAMPLING POPULATIONS

Visual counting and trapping are the most frequently used techniques for sampling field populations of cockroaches in efficacy research. Selection of a sampling technique involves decisions on a number of factors relative to various properties of available sampling methods and the conditions under which the sampling methods is to perform. The qualitative and quantitative information desired from a study must be carefully considered before deciding on the sampling technique(s) to be used. In some studies, more than on kind of sampling will need to be done, especially if both quantitative and qualitative information on a population is desired. Routinely implementing more than one sampling method has merit, although the cost of doing this may be prohibitive.

DATA ANALYSIS

The objective of a field efficacy experiment is to classify the control measures (groups) according to their performance on pest populations. The null hypothesis is that of no treatment difference, against the alternative that the treatments are not all equal. Also of interest is whether or not there is an effect of the group and time interaction (the residual nature of the insecticide treatment).

There are basically two approaches to analyzing field collected data, parametric and nonparametric statistics. Parametric tests are sometimes used; however, certain critical assumptions must be satisfied prior to use of these statistical tests. Nonparametric methods have the benefit of being designed to avoid most of these assumptions and are easier to compute. This overall efficiency and ease of use make the nonparametric tests desirable methods of analysis.

REPORTING

All of the information discussed in this paper should be reported so that data assessment and significance can be determined. There are a number of avenues for publishing efficacy information, and well designed efficacy experiments with appropriate data analysis should be published for use by appropriate audiences.

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PROBLEMS ASSOCIATED WITH EVALUATING COCKROACH CONTROL CHEMICALS - ETHICAL CONSIDERATIONS

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ABSTRACT

Within our science there have been few attempts to define or delineate what are considered ethical or unethical practices. In fact, there have been very few discussions as part of scientific forums wherein ethics has been a formal topic for consideration. It would appear to be appropriate that as part of the 3rd Urban Entomology Conference that an attempt has been made to introduce ethics both as a formal presentation and as a topic for discussion.

For the purposes of these discussions a differentiation has been made between researchers associated with industry and those working at universities or in other academic or public settings. It is recognized that demands may differ, but that ethical considerations are basically the same. There continues to be a need for "Good Science".

Keywords - Ethics, Research, Science, Testing.

RESPONSIBILITIES TO SOCIETY

Industry

It is critical that scientists involved with industry strive to provide pest control products that are both effective and safe to use. Any research involving the evaluation of active ingredients, formulations, and application procedures must provide for a large margin of safety for the general public. The public also deserves products that are effective as demonstrated under "real life" situations.

Advertisements for products must be based on good data. Claims of "out performs" should be documented through testing which utilized appropriate experimental designs. In some cases, it appears that there are disagreements within the same company, between researchers and marketing personnel when it comes to interpretation of test results. One can only hope that science prevails when the final decision is made.

The goal of any industrial experimentation is to eventually provide products that the public will buy and use safely and effectively. It is important that adequate and appropriate data be collected and made available to those individuals that wish to use the products. It is not enough to state that the product "is safe and, there have never been any reported problems with its use". Fact sheets, material safety data sheets (MSDS), and full labels need to be readily available.

Even though it is being discussed again, it is critical that scientists in industry continue to practice "good science". Those of us that work with our colleagues in industry know and appreciate their capabilities and resources; however, there are regulatory agencies and private citizens that consider industrial research as suspect, and self-serving. The only way to overcome this perception is to strive for excellence in the design and conduct of all investigations.

Academic (Research and Extension)

While the demands are different for the academic workers as compared to industry, the pressures to publish and secure funding potentially can influence the quality of research. It is of paramount importance that university research be as unbiased as possible and reflect "good science". The public has come to expect neutrality from these researchers, and conflicts of interest must be avoided. Utilization of the null hypothesis in experimental designs helps to insure this unbiased approach.

Interpretation of experimental results should be conducted from a neutral position. The source of funding that supports investigations should have nothing to do with the final outcome of those studies nor the recommendations produced by that research. Again, conflicts of interest must be avoided. The public interest must be served.

EXPERIMENTAL DESIGN

It appears that the use of the scientific method has been de-emphasized in recent years. Most scientists still adhere to the premise that all research starts with the formulation of a hypothesis from which the scientific design is then developed. Therefore, the end result is to either accept or reject the hypothesis and/or to pose an alternative hypothesis which must subsequently be tested.

Associated with the formulation of the hypothesis is the development of an appropriate test design, which includes considerations for the statistical analysis of the data collected. Many approaches can be taken in research designs, but the end result must be the collection of sufficient data to test the hypothesis. While this seems simple enough, all to often the test design and statistical analysis is not considered until after the initial trials (field or laboratory) have already been conducted.

There are a large number of statistical software packages available to scientists. Because of this, one of the specific problems that continues to plague our discipline is the misuse of statistical procedures. Some scientists run several statistical tests on data and report only those procedures that support their hypothesis. There are statistical packages available that will scan data and indicate which tests are most favorable to a stated position. This approach to statistical testing is not valid. Statistics should be considered a "tool" used in the interpretation of data. Slight differences in significance based on statistical testing should not overshadow that which is "biologically" important.

We may have reached the point in testing pesticide products that "standardized testing protocols" should be developed. These procedures could be included with those used by the American Society for Testing and Materials (ASTM). Associated with the development of these protocols would be the establishment of a committee to periodically review and comment on the procedures. At the present time, it is difficult to compare the results of tests conducted by different researchers. The development of standardized protocols will assist in solving this type of problem.

RESEARCH FUNDING

Funding for research and extension programs in urban entomology continues to be a major challenge. Many scientists must rely on support from pesticide manufactures and suppliers for the majority of their funding. While these sources are good in terms of applied research interests, there are few situations where funding from industry can be used for the basic research needed on many pest species.

Federal funding has been slow to develop; however, a competitive grant program for urban pest control research is being established. In some areas there are check-off moneys provided through surcharges on pesticide sales, termite inspections and treatments, and from licensing fees. This approach to funding needs to be further explored.

The charges for contract research need to reflect the true costs of doing the data collection and analysis. There are now several independent testing services available for contract research. They have voiced concern over the "under bidding" done by universities and governmental agencies. Regardless of who does the work, there are direct and indirect costs involved and these costs need to be reflected in the proposals.

The controversy over overhead charges continues. It does little but to complicate matters when a contracting company or agency indicates that it is "their policy not to pay overhead". The fact of the matter is that many researchers in public institutions are obligated to report all grant support and to provide overhead when required. To withhold this type of information would be considered less than honest on the part of the researchers staff or the contractors.

SECRECY AGREEMENTS

The desire on the part of industry for secrecy agreements continues to cause challenges for universities and public institutions. While it is recognized that industry needs protection while they develop ideas and products, those supported with public funds also have obligations to the institution and to those providing the basic support. Many would consider it the public's right to know what research is being conducted.

Secrecy agreements can adversely affect graduate students and faculty. Situations have arisen where students involved in proprietary research have learned that their work cannot be presented at scientific meetings, nor can a thesis be prepared that would have public access. Faculty also face the difficulty of having to prove their competency through presentations at professional meetings and publications in order to achieve promotion and tenure. While these situations may be extreme, problems of this type need to be anticipated and avoided.

PUBLICATION OF SCIENTIFIC RESULTS

The goal of science is to answer specific questions. If the answer to the question is not made available, then the question remains unanswered. Publications are a necessary means of providing information resulting from scientific research. Those involved in public institutions are required to publish results both to meet public demands for accountability, as well as, to further individual careers. It is recognized that demands on scientists in industry are quite different, but as colleagues we need to understand these difference and find a middle ground.

While it is generally recognized that publications are needed, we have not done an adequate job in developing outlets for research results in urban entomology. While the Entomological Society of America has a variety of professional journals, there have been difficulties on the part of some researchers in publishing their results. This has been due in part to the applied emphasis of their work and also because of infighting. This attitude appears to be both unjust and unwarranted. The role of the trade publications and technical journals has not yet been adequately defined, particularly in terms of providing for "peer reviews".

The quality of research needs to be reflected through carefully prepared and reviewed scientific publications. Contracting agencies and industries need to recognize the importance of publications and require formal reporting and publication of validated results.

Peer reviews conducted on manuscripts need to be objective and helpful. Reviewers need to recognize that quality scientific publications help to promote urban entomology. We need to be supportive of those working in this area, while at the same time insuring that good science has been achieved. This can be done when we treat each other as colleagues.

RESPONSIBILITIES OF CONTRACTORS TO RESEARCHERS

It is imperative that researchers have available to them all available information concerning the safety of products, devices or approaches, before the work in undertaken. In most situations it is recommended that the Materials Safety Data Sheets (MSDS) and proposed labels be reviewed before the work is initiated. Blind experimentation should be avoided, especially if the work involves potential exposure to technicians and the public. No research in urban entomology is so important that undefined risks to humans or the environment should be attempted. Emphasis must always be towards insuring safe working conditions for everyone involved in the studies.

Interpretation of results of properly conducted research should lead to the same conclusions regardless of who does the test. Selective use of data sets or suppression of pertinent data obviously should be avoided and discouraged. This approach is as unethical as changing data to support a hypothesis. Of particular concern to many researchers are advertising claims based on selective use of data or managed interpretations of results.

The last point is there should never be a relationship between the amount of funding for a research project and the expected results of that project. Positive results can never be guaranteed when the scientific method is applied appropriately.

RESPONSIBILITIES OF RESEARCHER TO CONTRACTORS

While researchers are to remain objective in their work, they need to recognize the importance of keeping their commitments to contractors. Reporting should be timely and project completion should follow an agreed upon time table. Results should be presented in an understandable way. Methods and procedures should be discussed and agreed upon prior to initiation of the work. In all cases, the best science possible should be expected. Contractors rely on the data developed by researchers, and every effort should be taken to insure that data collected is appropriate and complete and that error terms are identified.

IMAGE OF URBAN ENTOMOLOGY

While exact definitions of "urban entomology" have not been developed, it is apparent that recognition of this area of entomology has increased. The Urban Entomology Conference being held is an example of ways that by meeting together and discussing mutual programs we can further this area of science. Formal urban entomology conferences have now been a part of the National Entomological Society of America annual meetings for several years, and yet we still do not have formal status as a section. We need to work together to reach this goal. There obviously needs to be a balance between the basic and applied aspects of urban entomology. Participation in and support of ESA and other professional organizations is needed. We need to also be supportive of each other by offering encouragement, sharing ideas, and fostering the concepts of excellence in research, teaching, extension, and industry programs in urban entomology.

UPDATE OF THE FORMOSAN SUBTERRANEAN TERMITE

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DISTRIBUTION

Little has changed of the nation-wide distribution of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, for the last several years. With the report of *C. formosanus* in Auburn, AL (Sponsler et al. 1988), this termite is currently established in 13 locations (mostly urban) in the United States continent (Fig. 1). The distribution is confined in the southeastern United States and Hawaii as shown in Fig. 1. The northern boundary of the world-wide distribution of *C. formosanus* is 35° N latitude (Su & Tamashiro 1987). Winter temperatures of locations north of Memphis, TN (ca. 35° N latitude), are probably too low for *C. formosanus* establishment. Rainfall and relative humidity west of longitude 100° W (central Texas) are probably too low for the requirement of this pest. With the possible exception of infestations in heated homes in northern states or localized wet conditions in the West, we believe that *C. formosanus* will continue to be found exclusively in the southeastern United States.

In urban southeastern Florida where pest control operators have been alerted to the presence of *C. formosanus*, four structural infestations have been reported 1985-1989 from areas previously free of this pest (Fig. 2). The speed of spread by *C. formosanus* in our area, therefore, is ca. 2.5 km per year. Tamashiro et al. (1987), however, estimated that spreading by *C. formosanus* swarmers in Hawaii is <100 m every 5 years. Our faster rate may be due to the transportation of *C. formosanus* by man in the highly populated urban areas.

RESEARCH UPDATE

BIOLOGICAL INFORMATION

Population variation. There has been a suspicion that *C. formosanus* in the People's Republic of China may be comprised of several allopatric populations, or a complex of subspecies (Watson et al. 1984). Of the *C. formosanus* collected from Hawaii, Louisiana, and Florida, Haverty et al. (1990) found that cuticular hydrocarbon compositions of Hawaii and Florida populations were more similar than those of Louisiana origin. Agonistic behavior analysis among colonies of *C. formosanus* in Hawaii and Florida indicated two discreet populations of *C. formosanus* in Hawaii, while the more recently introduced Florida colonies have one common origin (Su & Haverty, unpublished data). In the United States, *C. formosanus* populations are characterized by distinct, isolated distributions (Fig. 1). Chemotaxonomic and behavioral assays may be useful to determine the similarity among sympatric and allopatric populations and reveal the historical origin and dispersion of *C. formosanus* in the United States.

Foraging dynamics. Due to their cryptobiotic behavior, research in the population ecology of *C. formosanus* has been limited. Li et al. (1976) used iodine-131 to trace the foraging galleries of *C. formosanus* in China. Lai (1977) estimated the populations of field colonies in Hawaii by a mark-release program. Because *C. formosanus* is typically found in urban environments in the United States, we designed an underground trapping system to monitor activities of this termite with minimum disturbance from urban dwellers (Su & Scheffrahn 1986). A study using this trapping system in combination with a multiple mark-release program revealed that field colonies of *C. formosanus* may contain ca. 1-7 million termites and may forage within an area of up to 0.36 hectars (Su & Scheffrahn 1988a). The

Fig. 1. Distribution of *C. formosanus* in the United States as of 1989.

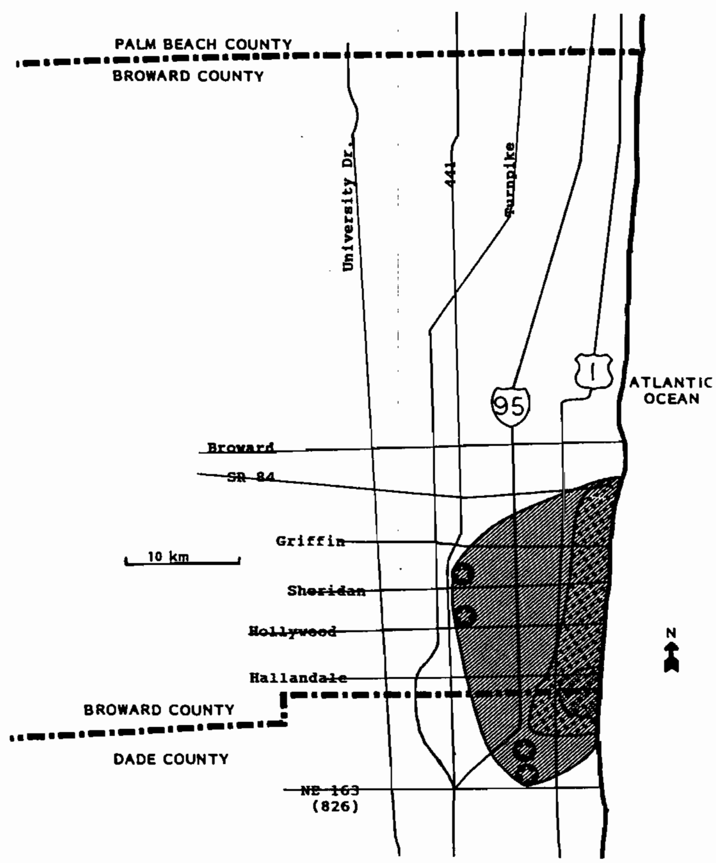

Fig. 2. Distribution of *C. formosanus* in urban southeastern Florida as of 1989 (indicated by shaded area). Stars denote four structural infestations reported between 1985-1989. Prior to 1985, alates were trapped within the area indicated by large points, while smaller area within verified ground or structural infestations (Thompson 1985).

results are comparable to those of Li et al. (1974) in China and Lai (1977) in Hawaii. Moreover, during the routine survey of *C. formosanus* foraging activities, we observed a fusion of two *C. formosanus* colonies, and intrusions of foraging sites of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), by *C. formosanus* (Su & Scheffrahn 1988b).

CONTROL MEASURES

Physical Control. Ebeling & Pence (1957) first suggested a physical control alternative when they discovered, in a laboratory test, that sand particles ranging in size from 10-16 mesh (equivalent to particle sizes 1.2-1.7 mm diam.) were not penetrated by the western subterranean termite, *Reticulitermes hesperus* Banks. Their observation indicated that the particles were too large for termites to manipulate yet were small enough that termites could not maneuver between them. This physical control technique, however, did not attract attention mainly because of the availability during the 1950s of inexpensive and effective soil termiticides such as chlordane and heptachlor. During a routine termiticide evaluation, Tamashiro et al. (1987) reconfirmed the finding of Ebeling & Pence (1957). Their results showed that the Formosan subterranean termite did not penetrate soil barriers composed of particles 1.7-2.4 mm in diam. A field study initiated in Hawaii demonstrated that sand barriers with the above specified sizes placed beneath structures proved effective in preventing invasion by *C. formosanus* for at least four years (M. Tamashiro, personal communication).

Apparently, the particle size required is dependent on the mandible and head capsule dimensions of the target termite species. Because there are three economically important subterranean termites in Florida (*C. formosanus*, *R. flavipes*, and *R. virginicus* Banks) (Scheffrahn et al. 1988), we are currently conducting studies to determine particle sizes for each species, and to evaluate modified techniques such as double-layer or mixed size barriers to be used when more than one subterranean termite species exists.

Soil Termiticides. For nearly four decades, two cyclodienes, chlordane and heptachlor, have been used extensively for subterranean termite control. The organophosphate, chlorpyrifos (Dursban^{R} TC), became available in 1980, but the cyclodienes continued to dominate the market share until their withdrawal in 1987. Between 1987 and 1988, over 75% of the PCOs switched from chlordane to new termiticides, mainly Dursban^{R} TC, according to a survey (Mix 1988). Currently, two organophosphates (chlorpyrifos and isofenphos) and three pyrethroids (permethrin, cypermethrin, and fenvalerate) are marketed for the pest control industry as termiticides under six brand names. In a laboratory study, we compared the efficacy of chlordane and currently available soil termiticides against *C. formosanus* and *R. flavipes* (Su & Scheffrahn 1990). The results showed that, when topically applied, chlordane was least toxic. As reported by Beal & Smith (1971), our results indicated that *R. flavipes* was more susceptible to termiticides than *C. formosanus*. Soil treated with chlordane was also most vulnerable to termite tunneling activity. Both termite species penetrated the 5 cm soil treated with 10 ppm of chlordane, while permethrin curtailed termite tunneling at 1 ppm.

Bait Toxicants. Currently, we rely exclusively on soil termiticides to control *C. formosanus*. The organophosphates and pyrethroids are used as toxic or repellent barriers between soil-borne termite colonies and structures requiring protection. La Fage (1986) estimated that soil termiticides are applied at a rate of ca. 390 kg/h beneath treated structures compared to agricultural rates of 2.17 kg/h (Pimentel & Levitan 1986). Despite the large quantities of pesticides used, soil treatments do not impact termite populations but only provide barriers to separate structures from soil-borne termite foragers. Colonies of subterranean termites, especially those of *C. formosanus* which may forage as far as 100 m from the central nest, remain viable near the structures even after treatment (Su & Scheffrahn 1988a). Because of the inability of current control techniques to reduce existing subterranean termite populations, severity of infestations by *C. formosanus* in areas such as Honolulu, HI, and New Orleans, LA, has escalated in recent years.

Use of a slow-acting toxicant may provide an alternative control to suppress the populations of *C. formosanus*. The principle of colony population suppression is to allow individual termites to acquire a lethal dose of slow-acting toxicant from a given foraging site. The individual then dies at a random location within the foraging territory. The slow-acting characteristic is particularly important because accumulation of a large number of dead termites at the toxicant acquisition site will prohibit other nestmates from further contact with the toxicant (Su et al. 1982). The toxicant has to be as acceptable to termites as other food sources, or must be masked by other agents to prevent termites' avoidance.

Laboratory studies indicated that hydramethylnon (Amdro[R], avermectin B_1 (Su et al. 1987), A-9248 (Abbott Laboratories) (Su & Scheffrahn 1988c), sulfluramid (Su & Scheffrahn 1988d), and insect growth regulators (IGR's) such as methoprene, fenoxycarb, and S-31183 (Sumitomo Chemical Co.), showed delayed toxicity against *C. formosanus* and the eastern subterranean termite, *R. flavipes* (Jones 1984, Su et al. 1985, Haverty et al. 1989, Su & Scheffrahn 1989). Evaluation of the repellent or feeding deterrent qualities of these compounds continues.

A field trial with hydramethylnon baits resulted only in partial control of *C. formosanus* colonies (Su et al. 1982). Between 1987-1988, we introduced A-9248 (Su & Scheffrahn 1988c) impregnated baits into foraging territories of three field colonies of *C. formosanus* in urban southeastern Florida. Although the foraging activities monitored throughout the bait trial period did not change drastically, mark-recapture programs conducted before and after the bait application revealed that the foraging populations of three *C. formosanus* colonies were reduced 75-98% (Su et. al., unpublished data).

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the thermodynamics and moisture flux of a structure. Architects understand this from an energy-efficiency standpoint. But their efforts to conserve energy actually *enhance* arthropod survival and allergen accumulation by reducing air exchange through air tight construction of homes. Working with architects, we hope to provide energy efficiency AND insect resistance to a new structure.

However, there are numerous buildings with current problems that need immediate solutions. Our research efforts are directed toward (1) eliminating current infestations, (2) preventing reinfestations, and (3) managing allergen levels. These latter two are designed to move the pest control industry, into a unique position to provide *preventive* measures rather than only *reactive* measures to "crisis" population levels. Among some possible advances in controlling arthropods and managing allergens, we anticipate use of patented repellents to deny access of these pests to specific areas conducive to their survival. Standard control practices likely will shift from use of irritating foggers and sprays toward effective use of baits. In the future, new industries and expanded operations may focus on allergen sequestering, allergen removal, and habitat modification through enhanced ventilation and use of repellents during construction with periodic maintenance applications.

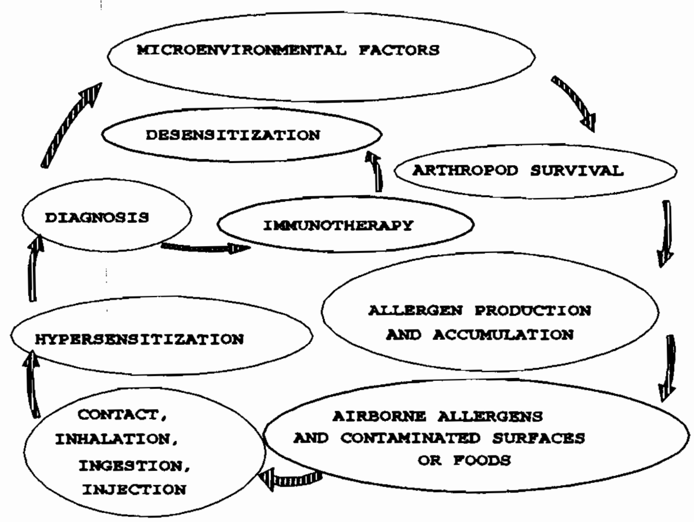

Figure 3. Overview of relationships. See text for explanation.

higher concentrations of foods, such as the stove, and areas with ample harborage space where air flow is minimal, such as beneath and behind cabinets, also provide stability. In the vertical dimension, soffits (also called overhangs, or eaves) have relatively high cockroach populations in addition to accumulated frass and cast skins of other insects. Cockroaches also use air stacks of sewage systems as conduits. Again, these relatively cooler surfaces will be the first to condense moisture, thereby providing the essential element of survival.

LEGAL PRECEDENT

The seriousness and significance of these arthropod allergens in the home now has a legal precedent, as well as vast medical precedents. A civil suit resulted from the death of a 31 year old male in Georgia. The plaintiff was his wife, filing a "wrongful death" suit on the basis of pesticide poisoning. His medical records were obtained and several salient facts were evident. He was a severe asthmatic with a documented serious allergy to "house dust". Furthermore, his wife testified that he had had a serious asthma attack just 6 weeks prior to his death, and that he was not under a doctor's care. It was revealed during the trial that, without treatment with corticosteroids, this decedent remained at an elevated risk as a result of that serious attack. Expert testimony concluded that the fatal attack was probably initiated by arthropod allergy and was unrelated to the pesticides.

In October, 1988, the jury ruled in favor of the pest control company, indicating that such was likely the case. This was appealed by the plaintiff, but the Appellate court affirmed the jury's decision in September 1989[4]. Therefore, although this was to the advantage of the pest control company in this instance, it also establishes a precedent stating that arthropod allergy --- or failure to manage arthropod allergens --- can have disastrous effects.

PROBLEMS AND SOLUTIONS: THE OVERVIEW

Fig. 3 illustrates the biotic and abiotic relationships concerning arthropod allergens and human health. As entomologists, we know that microenvironmental factors determine whether arthropods can survive. With survival, production and accumulation of allergens occurs. As the bulk of the frass, cast skins, and arthropod contaminants breakdown, the allergenic components persist, and many will become airborne via dynamic air flow patterns, heating systems, activities of occupants in the home, and probably a plethora of mechanisms. Over time, probabilities are high that occupants will contact, or ingest, or inhale these, and if they are genetically predisposed, hypersensitization can occur. Ideally, improved diagnostic procedures could determine precisely which proteins are causing an allergy, and with equally refined immunotherapy, desensitization may occur. However, in many cases, diagnosis is not made; medical attention is not sought, or immunotherapy is not successful. Consequently, any resolution of symptoms is contingent on avoiding allergens by managing the microenvironmental factors. In the case of house dust mites, this includes sealing the mattresses in plastic, along with the offending populations of mites and accumulated allergens. We view microenvironmental factors as the key to the solutions, along with improved diagnosis and immunotherapy.

Therefore, we have pooled research expertise from a variety of disciplines to examine air flow patterns, allergen production and accumulation and purification, the roles that home construction and environmental management play, and the role that people play -- both in encouraging arthropod survival, and in what measures people are likely to take to reduce health risks. We must understand

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4 Pamela Stiltjes v. RIDCO Exterminating Company, Inc.; Civil Action No. 86A06481, Superior Court of Gwinnett Co., GA.

hypersensitivity (determined by scratch tests) among Dominican children attending allergy and well-child clinics. This pilot study included 24 children from the allergy clinic, and about 50 from the well-child clinic. Several variables were measured via anthropological interviews of the parents. Quality of home was determined by scoring each structure by roof, floor and wall construction. Lowest quality would be a structure with a dirt floor, wood walls, and wood or tin roofing (relatively loose construction). Highest quality was characterized by masonry walls, floors, and roofs (relatively tight construction). Other variables also were examined, such as number of occupants per room, sanitation levels, and estimated income. The latter is hard to define in a developing country where unemployment, subsistence farming, and barter are common.

Quality of home was the only variable that was predictive for incidence of cockroach allergy (Fig. 2a). However, in this instance, higher quality was indicative of a greater incidence in allergy -- just the opposite of what would likely be seen in this country. The same trend was seen in mite allergy, but this is not statistically significant (Fig. 2b), probably because contents of homes were not scored. In terms of mite microhabitats, home articles, such as stuffed chairs, carpet, type of mattresses and pillows, would be better indicators. However, because contents likely correlate with quality of home, the trend is evident.

To understand these results, and the significance to our questions, we must understand some basic relationships in the home environment. Generally speaking, cockroaches and other arthropods avoid air flow. It is desiccating, and habitat stability decreases as air flow increases. In the range of homes studied in the Dominican Republic, lower quality homes were drafty, whereas better built homes were tighter with reduced air flow. This was a major benefit in conducting the study in the Dominican Republic. Within a small geographic urban area, the range of home quality is far greater than what could be found typically in the U.S. In better built homes, characterized by reduced air exchange with the outdoors, airborne allergens accumulate. In fact, arthropod allergy becomes more pronounced in the U.S. seasonally once windows are closed and heating systems are activated; forced air systems keep allergens circulating (Stankus & Lehrer 1987).

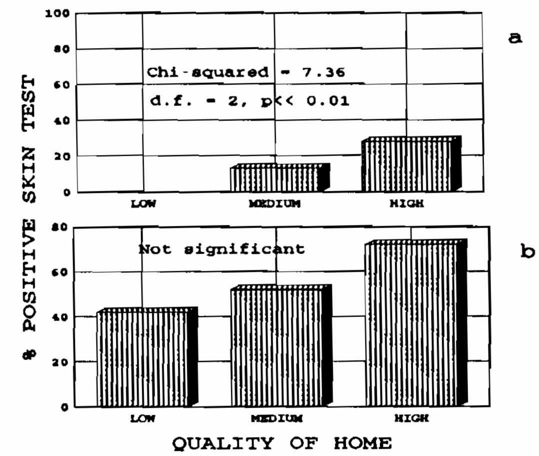

Figure 2. Relationship between quality of home construction and incidence of cockroach hypersensitivity (a), and mite hypersensitivity (b). See text for explanation.

Consequently, we conclude that as home quality --- and our standard of living increases --- so does incidence of allergy. Actually, there are two phenomena occurring. First, the better built home becomes a better habitat for arthropods, and second, with this tighter construction, allergens that are produced by arthropods accumulate. We speculate that in the U.S., virtually all the dwellings, whose occupants have been allergy tested in research, have high quality homes, as defined by the parameters in the Dominican Republic study. Differences in incidence of allergies by socio-economic level probably are dependent primarily by the *size* of infestations, rather than the suitability of habitat. This relationship between allergy and socio-economic status are clearly evident by the preponderance of data comparing allergy incidence in developing and industrialized nations (Massicot & Cohen 1986). Higher standards of living favor arthropod allergies. Therefore, we feel that arthropod allergen dynamics must be rigorously researched in the home environment.

Cockroach allergen will be most concentrated where the cockroach habitat is most stable, and consequently, where cockroaches spend most of their time. Areas associated with water or near water, such as the sink, dishwasher, and evaporator pan of the refrigerator will be stable foci. Areas with

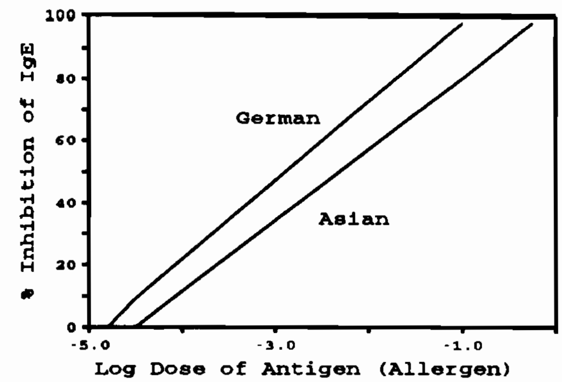

Figure 1. Cross-reactivity of Asian antigen with German IgE antibodies. See text for full explanation.

and the rural environs of Asia), Asian allergens will be bound by German cockroach IgE antibodies, and this would be expected to result in an allergic reaction in these persons. In yet another example suggesting the presence of generic allergens, entomologists who develop allergies to cockroaches find an additional concomitant allergy to shrimp and lobster, and some cross-reactivity has been documented in immunological assays (O'Neil et al. 1985).

There are two extraordinarily important points relative to these supposed generic allergens. First, developing any arthropod allergy is dependent on genetic predisposition of the individual, the species of arthropod and the size of infestations, and the duration of exposure to the allergens. Second, developing allergies to one insect or arthropod may result in cross-reaction to many species. Thus, the logical conclusion is to avoid developing the first arthropod allergy.

PROBABILITIES OF EXPOSURE TO ARTHROPOD ALLERGENS

Where are these first allergy exposures likely to occur? Some clues can be obtained from a historical perspective. During the past 20 years, allergists and pharmaceutical companies sought environmental causes of allergy unrelated to grasses, pollens, and pets. Dust was collected from homes without animals, and persons were found to be allergic to this conglomerate. In recent years, refined techniques in protein separation have shown that house dust mites and insect parts (primarily cockroaches) are the most common allergenic materials in "house dust" from homes without pets (Bessot & Pauli 1986). Therefore, persons with defined allergies to "house dust" likely have allergies to mites or cockroaches. If we can assume that we spend a significant proportion of our lives in our home environment, then either house dust mites or cockroaches are the most likely "first arthropod allergy" that we must avoid. Recent reports on the incidence of allergy to these arthropods (discussed earlier) tend to support this hypothesis.

Preventing these allergies requires careful consideration of two additional questions: *why* are we exposed to arthropod allergens, and what environmental factors can be used to predict onset of allergy to arthropods? In general, allergy to cockroaches within the U.S. is more common in urban low income housing, where cockroach problems are notorious and low-bid pest control contracts are required. Although this suggests that the standard of living may be the problem, other variables have not been examined.

Therefore, a pilot study was conducted in the Dominican Republic to examine (1) whether incidence is greater because of the ubiquitous nature of cockroaches in the tropics, (2) whether incidence of cockroach allergy could be similarly correlated to the standard of living (demographic variables, measured by housing conditions -- a wide range of home quality exists within the urban environment), and (3) whether environmental conditions in the home and demographic variables could be correlated to incidence[3]. The study examined the incidence and level of cockroach and mite

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[3] This study was headed by K.C. Barnes in pursuance of her Master's degree in anthropology, obtained in May 1989.

hypersensitivity, a variety of symptoms may manifest. Most persons reporting symptoms in occupational exposure listed several, including runny nose (67%), skin irritation (62%), eye irritations (61%), difficulty breathing (33%), and 3 instances of anaphylaxis (2.6%) (Wirtz 1980).

SOURCE OF ALLERGENIC PROTEINS IN ARTHROPODS

There have been several studies examining the general location of allergenic proteins within the arthropod body, although none has provided suitably controlled experiments. In preliminary studies we conducted with extracts from German cockroaches, the greatest reactivity of serum from a hypersensitive laboratory technician was to cast skins followed by frass. In contrast, serum from Chicago patients[2] scored highest to cast skins followed by whole bodies. To date, researches have reported 2-18 allergenic proteins in German and American cockroaches (Twarog et al. 1977, Wu & Lan 1988, Helm et al. 1988). Data suggest that the specific proteins to which an individual may develop allergies depends on several factors, including genetic predisposition of the person, species and extent of current infestations, and probably the history of infestations in a given structure.

House dust mite allergens are abundant in whole bodies of mites, feces, and cast skins. Allergen levels in structures are related to household furnishings and humidity levels (Pollart et al. 1987). Allergies from bites of adult fleas have been well known for decades (Trudeau et al. in press). Proteins in the salivary glands have been isolated and allergists have demonstrated these to be the cause. However, recent studies done in Florida have suggested that 2 major and 5 minor allergenic proteins occur in cast skins and laboratory rearing media of flea larvae (Trudeau et al., in preparation). Thus, the domestic environment with a current infestation or even past infestations of common arthropods harbors several allergens.

"GENERIC" ALLERGENS

These arthropod allergens may represent risks far greater than their individual effects. Baldo and Panzani (1988) published an article describing the frequency of multiple insect allergies. Of the 41 patients studied (36 of whom were asthmatic), 13 had significant skin-test reactions to all 7 species used in the study --- these insects represent 5 orders, including flies, moths, beetles, cockroaches, and caddisflies. The authors offer 2 possible explanations, (1) that separate allergies were developed to each species, which is highly unlikely, given the distribution of some of the species used, or (2) that IgE antibodies may cross-react widely with a variety of insects, crustacean, and other arthropods. The latter hypothesis is considered more plausible; although IgE antibodies bind to very specific allergens, there may be "generic" allergens common to many species, possibly associated with arthropod cuticle, proteins that function during molting, components of arthropod hemolymph, or digestive enzymes.

We have seen evidence of generic allergens in laboratory reactions of serum from the Chicago patients (mentioned above) to German and Asian cockroach antigens (Helm et al. in press). Figure 1 reflects inhibition of antibodies to German cockroaches by German and Asian antigens. This study determined whether antibodies, in persons with allergies to German cockroaches, bind to proteins from ground-up Asian cockroaches as well as to those from German cockroaches. The curve for Asian cockroach antigen is straight and parallel to the curve for German cockroach antigens, indicating that both species are producing similar allergens in similar quantities. Therefore, although these Chicagoans clearly have not been exposed to Asian cockroaches (known to occur only in Florida

[2] Serum was provided to R. M. Helm by Bann Kang, University of Kentucky.

profound. What social/cultural/medical changes have occurred in the past 25 years that would cause this? What can we expect within the next 25 years? Can we discover what causes these problems? How significant a role do arthropods play? Can we predict who will be at risk? What effects will this have on the pest control industry? Will the industry survive despite these trends or *because* of these trends?

ALLERGIES TO ARTHROPODS

Although allergies to many species of arthropods have been documented, house dust mites is the most common allergy among asthmatics (Hendrick et al. 1975, Kang & Sulit 1978). The principal offenders are in the genus *Dermatophagoides*. In various studies reported by Kang and her colleagues, 84% of asthmatics and 73% of non-asthmatic atopics exhibit this allergy.

Allergy to cockroaches is the second most common hypersensitivity among asthmatics, with 51% positive in standard skin scratch tests . Incidence among non-asthmatic atopics approaches 37%, and even 12.4 % of people without histories of allergies also exhibited cockroach hypersensitivity (Kang & Sulit 1978, Lan et al. 1988, Tuchinda et al. 1987). These data suggest that about 10-15 million Americans are allergic to cockroaches. Studies by Lan et al. (1988) and Tuchinda et al.(1987), conducted in Taiwan and Thailand, respectively, showed similar trends, illustrating that allergy to cockroaches is not an isolated problem.

MECHANISMS OF HYPERSENSITIVITY AND COMMON SYMPTOMS

Hypersensitization to allergens can occur via injection, ingestion, dermal contact, or inhalation. Injected allergens result when venoms or salivary proteins are introduced into the body through stings or bites. This is the mechanism associated with hymenopterous and hematophagous insects. Allergies to bee stings are common knowledge to most people, and it is well established that anaphylaxis can result in death within minutes of envenomization.

Ingested allergens are well known in cases of food allergies, and it has been suggested that this may occur as a result of ingesting arthropods that infest our food supply or contaminate it. The Indianmeal moth is the most frequent infestor of stored commodities, and allergies to this species are fairly common (Bernton & Brown 1967). In many locales, cockroaches commonly infest grain bins, warehouses, factories, restaurants, and food service equipment. Although this may be more important than is commonly believed, it would be difficult to demonstrate conclusively. In the context of arthropods, contact hypersensitization is a mechanism that is recognized but not well elucidated. Many research technicians and graduate students who spend much time handling insects develop contact dermatitis. Risks to homeowners is not known, but some allergenic proteins are persistent; Bernton & Brown (1964) have shown that some cockroach allergens remain potent despite 1 hr. at 100°C, suggesting that such materials may accumulate and be encountered by occupants over extensive periods.

Inhalation is the mechanism that is most pertinent to arthropod allergies. Its significance is well established, and bronchial provocation challenges are used frequently to unequivocally confirm allergy to specific proteins. Although allergenic proteins are too large to be volatile, allergens adhered to dust particles can become aerosolized and redistributed through normal air currents, static electricity, or during the act of cleaning (Pollart et al. 1987).

Occupational exposure to arthropods commonly results in hypersensitization. There is a long list of offending arthropods. Wirtz (1980, 1984) compiled a list of over 50 species incriminated in allergies among personnel in entomology laboratories. Any person chronically exposed to arthropods or their detritus are at risk of developing these occupational allergies. Once a person has developed immunological system over reacts to relatively harmless foreign bodies. Several terms must be defined in order to gain a rudimentary understanding of immunology[1].

Antibodies are molecules produced by the immune system that will recognize and combine with specific foreign bodies. Any foreign body that elicits the production of antibodies is called an **antigen.** Typically, these antigens are proteins with a minimum molecular weight of 5,000 daltons. There are 5 classes of antibodies, also known as immunoglobulins IgG, IgA, IgM, IgD and IgE. IgG is the most common antibody, and it freely circulates throughout the body. IgE is the least common antibody, and it tends to accumulate on specialized "mast" cells. In low concentrations IgE functions favorably in fluid transport across cell membranes, but in higher concentrations it is the culprit in allergic reactions.

Hypersensitivity, or allergy, is an inappropriate and excessive response of the immune system to harmless antigens. There are four types of hypersensitivity, but only Type I, also known as **immediate hypersensitivity** is relevant to this topic. In a case of hypersensitivity, the first encounter of the immunological system to a relative harmless foreign protein (such as in pollen) hypersensitizes the individual when large quantities of IgE are produced. In subsequent exposures, the binding of the antigen to the IgE results in release of histamines and other tissue-damaging substances by the mast cells. Antigens that elicit these allergenic responses are called **allergens.**

Persons who exhibit Type I hypersensitivity are generally considered atopic. **Atopy** is defined as the clinical feature of Type I hypersensitivity reactions, which include eczema (skin rash), asthma, and rhinitis (chronic "runny nose"), in a subject with a family history of such conditions. **Asthma** is a condition marked by recurrent attacks of shortness of breath with wheezing due to spasmodic contraction of the bronchi. In extreme instances, **anaphylaxis**, or shock, can result; antigens bind to the excessive IgE which initiates a release of histamines that dilate blood vessels, increase vascular permeability, and constrict smooth muscles --- among which are bronchi in the lungs. In localized reactions (such as bee stings), swelling is immediate. In systemic reactions, death can result.

INCIDENCE OF ALLERGIC DISEASE

How prevalent are allergies in general? What are the trends in incidence? Is it decreasing in this age of modern medicine? These questions were addressed by the National Institutes of Health (Massicot & Cohen 1986), and by The Asthma and Allergy Foundation of America (Annon. 1989). Unfortunately, their reports depict a grim trend.

Allergic disease is now recognized as a *major* health problem in the U.S., affecting about 17% of the population (about 37 million persons). Asthma occurs in at least 6.6 million persons, or about 3% of the overall population, and both frequency and severity have risen steadily during the past 25 years. Three million children under the age of 15 have asthma, another 6-9 million have allergic rhinitis, and another 2 million have atopic dermatitis. Childhood asthma has increased from 4.5% to nearly 8% during the 1970's. Asthma is more common in urban than rural dwellers, and it is the most frequent reason for emergency room visits in children. It is more common in young boys than in girls, but in adults, women predominate, and the most severe reactions relative to insects occur in persons over 30 years old. Annual deaths from asthma have been rising since the 1970's, and asthma caused by occupational exposures to allergens now accounts for 2% of all asthma cases (at least 132,000 persons).

These general trends are expected to increase when one considers current trends in demographics in this country; the average age is approaching 30, and over 80% of our population now live in urban centers. The majority of allergic diseases are not caused by arthropods, but recent studies clearly demonstrate that they are an important element at the very least, and that the implications are

[1] All definitions are according to Roitt et al. 1989.

ARTHROPOD ALLERGENS IN THE URBAN ENVIRONMENT

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ABSTRACT Advancement from a developing to a developed nation alleviates the effects of disease brought about by pathogens, but creates an environment conducive to fostering allergic diseases. Allergies to arthropods are now recognized as a significant health threat; house dust mites and cockroaches lead the list of offenders. A review of literature, results from laboratory research and from an overseas pilot study indicate that the home environment exposes us to arthropod allergens, and that developing the first allergy may result in broad cross-reactivity with other arthropods. Therefore, prevention of the first allergy is paramount. Preventive measures should address (1) better methods to eliminate arthropod infestations while managing allergen levels, (2) preventing infestations through manipulation of the microclimate in structures, (3) and use of novel repellents to render microhabitats inhospitable.

Keywords - German cockroaches, house dust mites, insects, repellents, baits

From a cultural viewpoint, mankind's evolution from a nomadic hunter-gatherer to an anchored tender of animals and crops enhanced long-term prospects for survival. Along the way, communities were formed and structures were developed to provide protection from the ravages of climate and predators. Modern medicine reduced many potentially fatal health risks to minimal concerns, and modern technology has allowed the construction of sealed, environmentally controlled homes and businesses. Unfortunately, from a biological viewpoint, these advances have exposed us to other elements causing additional tangible health risks -- allergens in the urban environment. This paper examines the trends and causes of allergic disease, the role of arthropods in allergies, and projected roles of the pest control and construction industries in safeguarding our health from these threats.

BASICS OF IMMUNOLOGY

Ironically, the immune system --- the one biological system designed to safeguard health --- is central to the problem. Immunology is a complex science that focuses on the defense mechanisms which protect us from the hostile world of pathogens and parasites. Allergy results when the

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The ability of permethrin to penetrate structural wood has been reported by Baker and Berry (1980). They investigated the distribution of permethrin in a radial direction in Scots pine one, six months and one year after a dip application. Data showed limited depletion in the outer 0-2 mm. The concentration of permethrin in the 2-4 mm zone showed no depletion, and there were indications that the concentration of permethrin in this zone increased during the ageing period.

Berry (1977) reported solvent-based solutions of 0.5%-0.02% permethrin applied to Scots pine to be toxic to larvae of old house borer, common furniture beetle, and powderpost beetle (Lyctus sp.). Permethrin 0.2% prevented common furniture beetle emergence 5 years after treatment. Baker and Berry (1980) reported permethrin equal to benzene hexachloride (HCH) in toxicity to first-stage old house borer larvae. Against medium to full-grown larvae of the common furniture beetle, permethrin was less toxic than HCH. They reported permethrin to be effective in preventing emergence of adult beetles, and may act in disrupting larval feeding activity.

Bato et al. (1982) reported on the toxicity of decamethrin (as Cislin, NRDC 161) treated wood to lyctids (Minthea spp.) and a bostrichid (Xylopsocus sp.). The wood was dip treated, and concentrations as low as 0.005 provided control after 3.5 years. Baker and Berry (1980) reported on the toxicity of decamethrin to old house borer larvae.

Baker and Berry (1980) reported cypermethrin to be more effective than permethrin after 12 and 24 weeks of ageing on glass plates. They reported that 0.1% cypermethrin prevented emergence of adult old house borers from blocks 12-18 after treatment. Berry (1984) reported cypermethrin to be twice as effective as permethrin against both common furniture and old house borer, and as toxic as lindane to these beetles. He reported cypermethrin to penetrate at least 3 mm into wood using immersion or vacuum methods. Berry (1984) reported 0.1% cypermethrin (19:1 emulsion) to be effective in preventing emergence of common furniture beetles 62 months after treatment and exposure to unheated, ventilated building.

SUMMARY

The application of wood-protection chemicals to the surface of structural wood, either by immersion or topical application, results in penetration of the outer 1-4 mm of wood. The outer 1-2 mm of treated wood rapidly become depleted of the chemical during the early stages of post-application exposure. Although the outer 1 mm experiences evaporative and degredational losses, the initial amount of chemical deeper in the wood changes very little. Estimates of the long-term effectiveness of a wood-protection chemical must be based on its ability to penetrate below a 1 mm evaporative zone and establish a layer of concentration at 2-3 mm in the wood.

Under normal conditions the moisture content of wood-in-use can range from as low as 6-7% (January, February) to a high of 13-15% (August, September) (Bois 1959). Chemical treatment for wood-infesting insects may occur throughout the year. Dodson and Robinson (1988) reported the impact of wood moisture content on penetration of 1% chlorpyrifos in southern yellow pine was insignificant. Powell and Robinson (1989) reported that there was no advantage to applying chlorpyrifos (as Dursban TC) to the point of run-off when treating structural timber. Spraying to run-off, although providing an initially high surface concentration, did not result in a concentration of insecticide at a depth of 950-2000 microns greater than application at 50 to 100 times less than run-off volume. Early instar old house borer larvae often feed within 2 mm of the surface of wood. The ability to get an insecticide to this depth is not based on the quantity applied to the surface (Powell and Robinson 1989).

Powell and Robinson (1989) expanded the work on penetration and permanence of chlorpyrifos by investigating the impact of different species of wood, and longer household-environment exposures. Penetration into four wood species, western hard pine, (Pinus sp.) southern yellow pine, spruce, and Douglas fir was evaluated at 24 h, and at six months in an attic and crawl space. The data indicate chlorpyrifos penetration into souther yellow pine was less than the other three species. However, at approximately 1 mm below the surface the concentration of chlorpyrifos was significantly greater in southern yellow pine than the other species (Powell, unpublished data).

The longitudinal movement of solvent-based chlorpyrifos when injected under pressure (150 psi) in Douglas fir and southern yellow pine was evaluated by Powell and Robinson (1990). Solvent-based chlorpyrifos, injected into the center of 2 in. x 4 in. (8.5 x 3.7 cm) structural timber, moved longitudinally at least 14 in. (35 cm) to the ends of the treated pieces. Gas chromatography analysis indicated that the chlorpyrifos/solvent penetrated to the ends of the timber (Powell and Robinson, unpublished data).

PYRETHROIDS

Soon after the discovery of pyrethroids at the Rothamstead Experimental Station (Elliot et al. 1973, 1974), they were evaluated for their potential in preventing or controlling wood-infesting beetles. Early investigations for control of the common furniture beetle and old house borer included permethrin, cypermethrin, decamethrin, and fenvalerate (Berry 1976, 1977, 1984, Bato et al. 1982). Permethrin and cypermethrin have been the pyrethroids most throughly tested for commercial development (Baker and Berry 1980). Early tests with fenvalerate indicated that it had unacceptable permanence in structural wood (Baker and Berry 1980).

wood and moved longitudinaly (Orsler and Stone 1982). Becker (1966) reported that surface-applied lindane would remain effective for 10-12 years against the old house borer. Hawkes (1973) predicted lindane to be effective for 30 years against the common furniture beetle.

ORGANOPHOSPHATES

Several organophosphate insecticides have been evaluated for controlling wood-infesting insects (Baker 1972, Metzner et al. 1977). Chlorpyrifos (Dow Chemical Co.) was first synthesized in 1961, and since then it has become one of the most commonly used insecticides in the world. Chlorpyrifos, formulated as a macroemulsion or as a microemulsion is labelled and approved by the EPA for use to control insects beneath the surface of structural wood in living areas of houses. These formulations are currently used for prevention and control of wood-infesting beetles in the families Lyctidae, Bostrichidae, Anobiidae, Cerambycidae, and Scolytidae. Insecticidal properties of this chemcial were described by Kenaga et al. (1965). Schaefer and Dupres (1970) reported the high degree to which chlorpyrifos adsorbs to organic solids. Brady et al. (1980) and Bush et al. (1987) reported chlorpyrifos more persistent in wood than lindane. Berisford et al. (1981) reported half-lives of 1, 3, 4, and 8 months for 1% and 2% aqueous chlorpyrifos on pine bark. Rose et al. (1984) reported on the penetration and residual activity of chlorpyrifos when pressure injected into wood.

The penetration and permanence of chlorpyrifos in structural timber, primarily southern yellow pine (Pinus sp.) and Douglas fir (Pseudotsuga menziesii (Mirb.)), has been investigated by Dodson and Robinson (1988) and Powell and Robinson (1989). They reported the ability of emulsion- and solvent-based delivery systems to penetrate wood, the impact of wood moisture content on penetration, and short-term permanence of chlorpyrifos (Dodson and Robinson 1988). Evaluation methods included treating the tangential surface of small blocks with a quantity of insecticide equal to run-off volume, then taking 50 micron slices from the treated surface of blocks down to about 2 mm. The amount of chlorpyrifos in each slice was measured by gas chromatography.

The influence of environment on permanence of 0.5 and 1% chlorpyrifos in the outer 1 mm of treated pine timber was reported by Dodson and Robinson (1988). After six months the amount of chlorpyrifos (applied at 1%) per mg of wood in the outer layer (50 microns) decreased from 4.434 mg at 24 h after application to 0.191 mg after six months in an attic environment, and to 0.612 after six months in a crawl space environemnt. At 0.4 to 0.6 mm below the surface the amount of chlorpyrifos remained relatively stable for six months, and showed little response to environmental conditions.

Guillemain-Thevenot et al. (1972) investigated penetration of 2% lindane and 5% dieldrin when pressure-injected into Scots pine, Pinus sylvestris L., the major construction timber in Europe. Following treatment, wood pieces were sectioned into 23 zones (about 3 mm thick) and the amount of insecticide in each zone was determined. They reported that the largest quantities of insecticide were found in outer zones of the wood, and only limited amounts of the two chemicals penetrated to the center of treated wood blocks (Guillemain-Thevenot et al. 1972). Romeis et al. (1974) reported on penetration of 4% and 5% pentachlorophenol and 0.6% and 1% lindane when pressure-injected into Scots pine and spruce.

Morgan and Purslow (1973) investigated volatile losses of pentachlorophenol and benzene hexachloride (BHC) from the outer 1-2 mm of Scots pine. They reported that 0.5% BHC quickly depleted from the outer 2 mm of treated wood, but insecticide at greater depths remained unchanged for several months. There was very little change with 5% pentachlorophenol, but this may have been the result of the higher concentration used, or an interaction with the wood. Morgan and Purslow (1973) also reported significantly less penetration of spruce with either BHC or pentachlorophenol. Orsler and Stone (1982) dip treated Scots pine in dieldrin and BHC, then placed the wood in a house "attic" for 5.5 years. They confirmed the surface depletion reported by Morgan and Purslow (1973), they expanded evaluation to 66 months, and examined the influence of emulsion- and solvent-based formulations on wood penetration of lindane and dieldrin. Solvent-based formulations showed penetration characteristics better than emulsion-based formulations. However, the oil and water-based emulsion resulted in the highest concentration of lindane and dieldrin in the outer 0.5 mm of treated wood.

The impact on old house borer larvae of pentachlorophenol vapors within wood treated by topical application was investigated by several workers at the Center for Wood Technology in Paris (Jacquiot and Serment 1971, 1973, Jacquiot et al. 1974). Analysis of dead, dying, and living larvae and their distribution to the nearest treated surface showed that mortality is independent of distances (Jacquiot and Serment 1971). In most instances the majority of dead larvae were found beyond the limit of penetration of the liquid phase of pentachlorophenol, and the vapor phase was suspected as providing mortality (Jacquiot and Serment 1971). The effect of lindane- and pentachlorophenol-treated wood on oviposition behavior, eggs, and first-instar larvae of the old house borer was investigated by Serment (1986).

Orsler and Stone (1982) reported on penetration of lindane into Scots pine infested with the common furniture beetle, A. punctatum. They found no improvment in penetration (radial surface) deep into wood, but they did find the outer 2-3 mm better treated than uninfested wood below the surface. Probably the liquid insecticide filled adult beetle emergence holes, then intersected with tracheid cells and ray cells in the wood-destroying organisms from structures. The cost of termite control in the U.S. exceeds $1 billion annually. In the United Kingdom more than 100,000 houses are treated annually for remedial control of the common furniture beetle, Anobium punctatum L.

Before the availability of modern insecticides, a variety of nonchemical methods were utilized for controlling wood-infesting Coleoptera. Heat treating and removing infested wood was sucessfully used in Europe in the 1920's and 1930's for controlling old house borer (Jensen-Storch and Hendriksen 1932). Williams (1977) reported on the response of Xyletinus (= Euvrilletta) peltata (Harris)) to high temperatures.

Prevention and control of Anobiidae, Cerambycidae, and Lyctidae in wood-frame structures around the world is now based on an insecticidal gas, or the application of a liquid insecticide to the surface or subsurface of wood. The objective of liquid application strategies is to contact and kill one or more of the life stages of the infesting insect, and to protect wood from further attack by leaving a toxic residue. The effectiveness of this strategy is based primarily on depth of penetration of a toxic dose of insecticide, and the degree of permanence acheived by the chemical and application method. Insecticides used to control and protect structural wood from insect attack include chlorinated hydrocarbons, organophosphates, carbamates, boron compounds, and pyrethroids.

CHLORINATED HYDROCARBONS

Chlorinated hydrocarbons were perhaps the first class of modern insecticides used for wood protection. The most common chemcials used are pentachlorophenol, benzene hexachloride (BHC), lindane (HCH), and dieldrin.

In 1936 pentachlorophenol was prepared commercially as a fungicide and insecticide in the United States and other parts of the world. However, data on the effectiveness of this chemical to control wood-infesting beetles was slow to develop. Durr (1954) worked with several species of softwoods and reported approximately 1.7 cm penetration when small, pine (Pinus spp.) blocks were immersed for 45 min in 5% pentachlorophenol. The majority of the chemical was deposited in the outer 0.2-1.0 cm of the blocks. Penetration was distinctly reduced in spruce (Picea sp.) blocks treated similiary.

Durr (1954) reported that in blocks treated 11-months previously with 5% pentachlorophenol, mortality ranged 53-82% for first-instar old house borer, Hylotrupes bajulus (L.), larvae inoculated into the blocks. There was 100% mortality of larvae inoculated into the BHC-treated blocks. Pine blocks immersed in 5% BHC remained toxic to first-instar old house borer larvae for 3 years (Durr 1954).

PENETRATION AND PERMANENCE OF WOOD-PROTECTION CHEMICALS

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ABSTRACT The control of wood-infesting beetles and the protection of structural wood from further attack is based primarily on surface and subsurface application of residual, liquid insecticides. The depth of penetration and degree of permanence of wood-protection chemcials is variable, and depends on the wood species, the insecticide and solvent, and application method. Lindane (BHC), dieldrin, and pentachlorophenol are depleted from the outer 1.0-2.0 mm of pine within three months after treatment. Pine blocks immersed in BHC remained toxic to old house borer larvae for three years. The vapor phase of pentachlorophenol may cause mortality of old house borer larvae in treated wood. Chlorpyrifos penetrates the outer 1.0-2.0 mm of pine, but the surface concentration is depleted in 3-6 months. The concentration of chlorpyrifos remains stable at the 950 micron depth in pine. Wood-moisture content does not impact on the penetration of chlorpyrifos in wood. The pyrethroids permethrin and cypermethrin penetrate the outer 1.0-2.0 mm of pine, and concentrations at the surface are higher than chlorpyrifos after 2 months.

Keywords - wood penetration, insecticide permanence, old house borer, common furniture beetle,

The protection of structural wood from attack by fungi and insects is important in modern society. Important not only for aesthetics and to maintain the structural integrity of residential and commercial buildings, but to protect a large, and often extended, financial investment. Preference and availability of wood as a building material has changed little over the years, but the initial and replacement costs for housing have risen sharply. The median cost of a new, single-family dwelling in the United States was $143,000 in 1989. Clearly, there is considerable incentive to prevent or eliminate

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IMPACT OF COCKROACH ALLERGENS ON HUMANS

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Introduction

Cockroaches have existed on this planet for millions of years. Some have speculated--sardonically--that cockroaches would be the only survivors of an all-out nuclear war. Their longevity is due in part because they are omnivorous, propagate relentlessly and withstand most forms of extermination.

The pervasiveness of cockroaches and resulting infestations have been associated with the development of hypersensitivity diseases, or allergies, in human. These allergies are similar in nature and severity to those induced by pollens.

Urban dwellings and public food handling facilities are notorious for high rates of cockroach infestations (1-9). Cockroach species most closely associated with human dwellings and/or occupational environments include *Blatella germanica, Periplaneta americana Linneaus, Blatta orientalis Linneaus, Periplaneta australisiae Fabricius* and *Supella Supelldeium Serville* (1-3). The species and rate of cockroach infestation varies, depending on the geography of human habitats and socioeconomic factors. Because cockroach infestation has become rampant, especially in urban areas, the resultant cockroach hypersensitivities and related diseases in humans have become serious medical problems.

Prevalence of Cockroach Hypersensitivity

Although cockroaches have long been considered vectors of various infectious diseases, they were not implicated in allergic conditions until 1943 when Lerner (10) reported generalized urticarial rashes following exposure to cockroaches. Linear dermatosis was reported after exposure to cockroaches by Simon in 1952 (1). There have been numerous reports by observers that workers in agricultural departments and scientists in the laboratory working with various cockroaches develop dermatitis and allergic respiratory symptoms (1,11,12). Recently, entomologists surveyed occupational allergies to arthropods among the workers handling the insects and reported that 12-33% of those surveyed had dermatitis along with respiratory allergic symptoms (11). Anaphylactic reactions, along with bronchial asthma, have also been reported after occupational exposure to Periplaneta americana and Blatella germanica (13).

Allergy skin testings were used to determine cockroach hypersensitivity in 1959 by Wiseman et al. (14), and the medical significance of cockroach hypersensitivity was suggested by Hellereich in 1962 (15). In 1964, Bernton and Brown (16) reported a high prevalence of cockroach hypersensitivity among atopics which was passively transferable by Prausnitz-Kustner test. They speculated that the sensitization of atopic populations toward cockroach-derived materials might occur by inhalant exposure or by ingestion of food contaminated by the insects. Bernton and Brown (17) also reported that the rate of cockroach sensitivity among the atopic population in New York City correlated well with the degree of pest infestations in their dwellings. Cockroach hypersensitivity in four ethnic groups, Puerto Ricans, Negroes, Italians and Jews were 59, 47, 17 and 5%, respectively. These reports mirrored the order of the severity of cockroach infestation among the ethnic neighborhood in New York City (8). Thereafter, more reports on cockroach hypersensitivity have been reported from other parts of the US (18-20), as well as other countries (21-23).

Table 1
Prevalence of Cockroach Sensitivity by Skin Testing in Various Regional Groups[a]

Area	Asthmatic population	Atopic population	Nonatopic population
New York City[b]	219/448 (49%)	257/755 (44%)	19/253 (7.5%)
Puerto Rico[c]	88/170 (52%)	130/284 (46%)	
Chicago[d]	94/153 (61%)	118/222 (53%)	17/63 (27%) (children)
Boston[e]	--	56/288 (20%)	--
Chicago[f]	283/680 (48%)	--	--

[a] Number of positive reacting subjects/total studied subjects.
[b] Quoted from Bernton and Brown (17).
[c] Quoted from Marchand (21).
[d] Quoted from Kang and Sulit (18).
[e] Quoted from Twarog et al. (20).
[f] Quoted from Veres et al. (37).

Table 1 shows a comparative prevalence of cockroach hypersensitivity by skin testing reported by different investigators from various geographic locations. The incidence of cockroach hypersensitivity is high among virtually all urban communities, although there were some differences noted among different locales as well as ethnic groups. Generally, low prevalence was reported in the suburban population (19,21,24,25). These reports, however, often cannot be compared directly, because investigators have used extracts of different species and/or different potencies for testings. Nevertheless, data indicated that the incidence of cockroach hypersensitivity was invariably high in comparison with prevalence of pollen sensitivities (18,25). The noted high rate was even higher in asthmatic groups than in general atopic group of the same urban populations (see Table 1). Schulaner (24) reported that 79% of positive reactors were found among asthmatic children whose dwellings were visibly infested by cockroaches. Kang and Sulit (18) noted cockroach sensitivity in 60% of the studied population and was the second most prevalent allergen demonstrated (exceeded only by house dust) among 11 groupings of 25 individual inhalant antigens tested.

Furthermore, it has been reported that cockroach allergy appears as a sole positively reacting aeroallergen of a group of allergens tested in atopics (17,21) and in asthmatics (26). Bernton and Brown (17) reported that many (i.e., 70 out of 170) nonreactors toward common inhalant antigens showed an isolated response to cockroach extract, although they did not elaborate its significance any further. Young children also show significant cockroach hypersensitivity (24,25,27), and the youngest showing such sensitivity was a 10-mo-old asthmatic boy (18).

Recently, Kang et al. (28) also reported that the prevalence of cockroach hypersensitivity is closely related to the rate of cockroach infestation in the dwellings of the asthmatic population. The house dust collected from the infested dwellings contained a high quantity of cockroach antigens (29,30), and the indoor air was contaminated by cockroach antigen (31).

Cockroach Asthma

In 1972, Bernton, McMahon, and Brown (32) reported that inhalation of cockroach extract induced coughing and breathlessness in all ten asthmatic subjects with cockroach positive skin reactions. Six of the ten subjects tested showed immediate bronchospasm objectively by reduced lung function ($\Delta FEV_1 > 15\%$). Consequently, the term "cockroach asthma" was coined. However, Uy et al. (33) reported in a bronchial challenge study that, except for one child, the 13 asymptomatic asthmatic children with positive skin test to cockroach antigen failed to show decreased airway conductance. They concluded that cockroach antigen was not an etiologic factor of the bronchial asthma among their asthmatic children.

Kang et al. (26,34), however, clearly defined the cockroach asthma by controlled bronchial provocation testings. Inhalation challenges of cockroach antigen on 28 cockroach positive and 10 cockroach negative asthmatics documented that cockroach asthmatics develop antigen-specific immediate asthmatic response following the antigen challenge (see Fig. 1). Cockroach antigen, 400-800 U (PNU) inhalation produced acute immediate asthmatic reaction in 90%, and late asthmatic reaction in 68% of cockroach

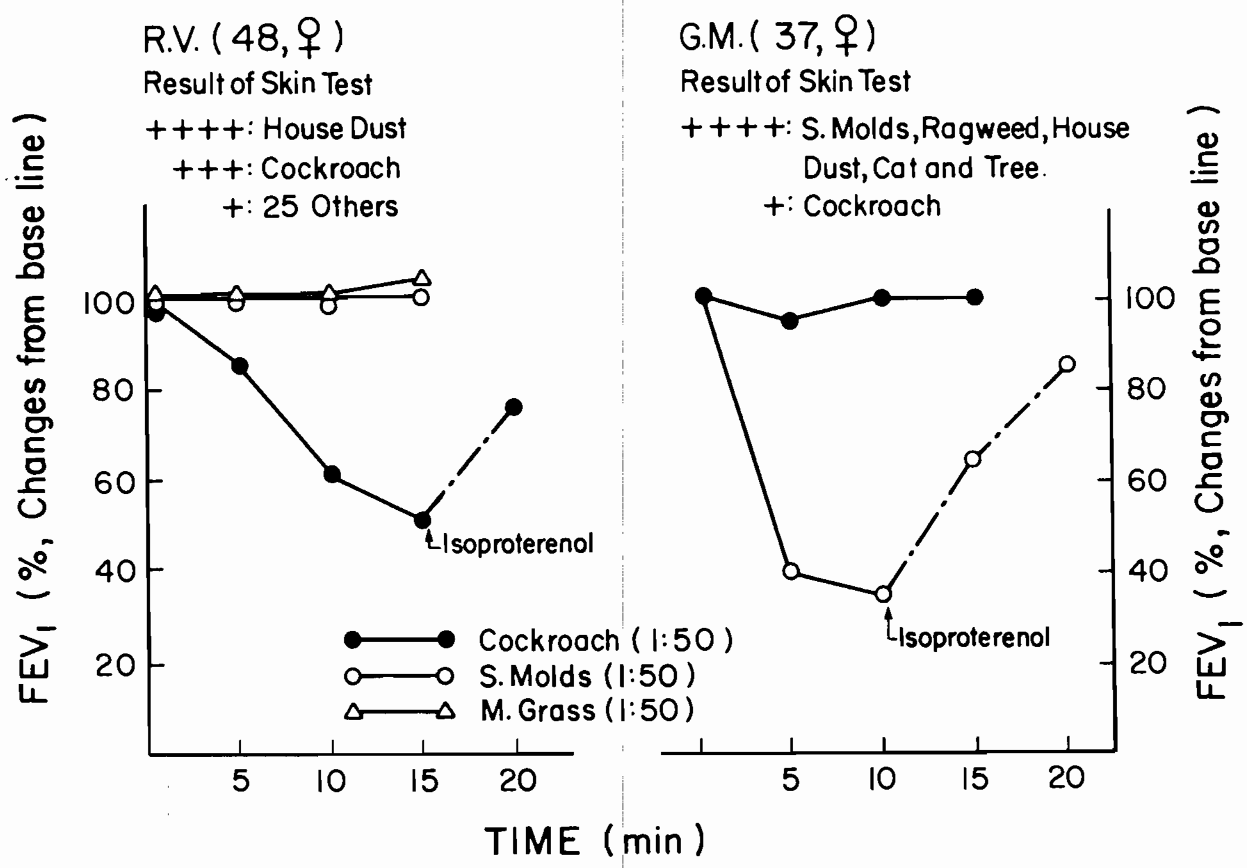

Fig. 1. Typical examples of change in forced expiratory volume in 1 s (FEV_1) following cockroach extract (CR) inhalation, compared with the effect of other antigens on two allergic asthmatic subjects. Approximately 400 PNU of each antigen was administered. Patient R.V. (left) was allergic to cockroach and house dust, but not to seasonal mold and mixed grass antigens. She had a marked decrease in FEV_1 (to 48% of baseline) following the CR challenge, but showed no change following the seasonal mold or mixed grass challenge. Patient G.M. (right) was allergic to many antigens, including seasonal mold, but not to CR. Inhalation of CR failed to induce any change, whereas seasonal mold caused marked reduction in FEV_1 (reported by permission) (34).

sensitive asthmatics. This indicated that cockroach antigen was inducing dual asthmatic responses following the experimental antigen exposure. None of the cockroach negative asthmatics developed either reaction. The antigen-specific asthmatic reactions were blocked by premedication of the cromolyn sodium (26). Moreover, the cockroach antigen challenge produced a significant antigen-specific peripheral eosinophilia in cockroach asthmatics, which progressed to its peak 24-36 hours following the antigen exposure (26,34). Local eosinophilia was also noted

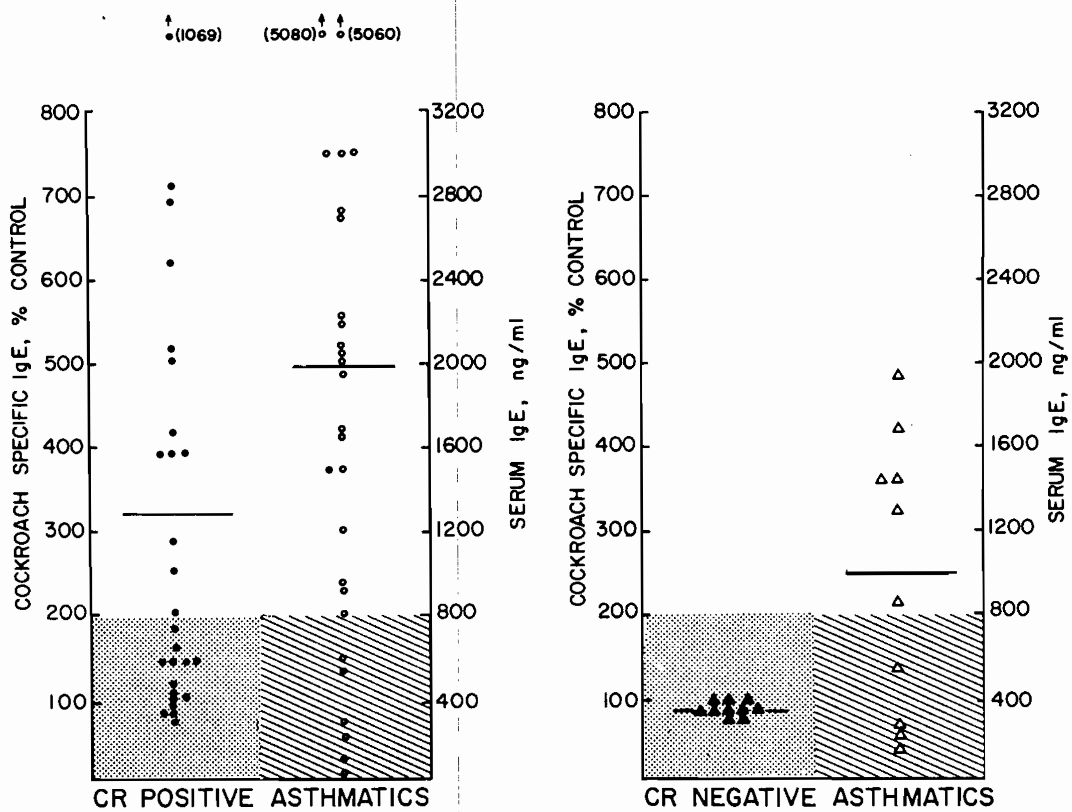

Fig. 2. A comparative serum levels of cockroach-specific IgE (●) (cockroach-RAST) and total serum IgE antibodies (O) of the 28 cockroach positive (Left +) and those (▲and △) of the 10 cockroach negative asthmatics (Right +) studied.

—— geographic mean
normal range of cockroach RAST
normal range of total serum IgE antibody

at skin window sites upon topical instillation of cockroach antigen (35). The antigen induced immediate bronchospasm coincided well with the sharp rises in free histamine levels in the peripheral circulation of the cockroach asthmatics (36) (Fig. 3).

Kang et al. (34) established that cockroach asthmatics had high levels of circulating cockroach antigen-specific IgE

●- - — - — - ●) following control and cockroach antigen (CR) challenge in 13 cockroach asthmatics. Pulmonary function changes are depicted as percent of baseline values. An instantaneous rise of free histamine occurred, reaching a peak level within 5 min after antigen inhalation. Ten subjects received 400 PNU of CR, 2 received 800 PNU, and 1 received 1200 PNU (reproduced by permission) (36).

Cockroach Antigens and Allergens

Extracts of three more common species of cockroaches (the American, the German and the Oriental) are fairly well studied for their antigenic and allergenic properties (20,29,30,38-42); extracts, in general, contain a pool of antigens and allergens similar to other allergenic extracts. There are cross-reacting antigens and allergens among extracts of the three species (38,42). However, there are substantial species differences noted in their allergenic potencies by allergy skin testing, in vivo (21), by RAST assays (39,40) and by Western blot analysis. Marchand (21) reported that the extracts of three species showed different allergenic potencies noted in allergy skin testing on 130 subjects, the highest was American, and German and Oriental cockroaches, in a decreasing order. These were noted among atopic subjects from Puerto Rico where dwellings were infested heavily by American cockroaches. Richman et al. (39) reported that direct RAST potency of the whole body extract of the German cockroaches was high indicating highest amount of allergens, while relatively less allergenic potency was noted in that of the American cockroach using 13 allergic patients' sera from Washington, DC. They also noted that cast skins, egg shells and feces of two insects contained allergens, in a decreasing order (40). Stankus and O'Neal (38) reported that the American and German cockroaches share common antigens and allergens. They reported that there were very similar allergenic potencies in the whole body extracts of the American and German cockroaches using 10 allergic subjects from New Orleans.

Attempts have been made to isolate major allergen(s) of the cockroach extracts (20,29,41). Twarog et al. (20) identified that the major allergen of the whole body extract of the American cockroach was contained in two fractions filtrated by G-75, Cr I and Cr II, approximate MW. 64 Kd. and 25 Kd., respectively. Cr I elicited 70% positive skin test while Cr II, low molecular weight allergen, was highly acidic and heat resistant. Stankus and O'Neal (38) studied further that allergenic activity of American cockroach extract was highest in fraction 2, but fraction 1 of the G-75 filtrate showed high RAST inhibition. They also identified that there were five electrophoretically distant allergens in the whole body extract of the American and German cockroaches using crossed radioimmunoelectrophoresis (CRIE).

Meanwhile, Chang et al. (29) investigated allergens of the cockroach extract mixture, equal parts of the American, German and Oriental cockroaches instead of studying the extract of a single species, with a rationale that atopic humans are likely exposed to the mixed infestation of the insects. They reported that major allergen(s) were in the high molecular fraction, B_1 when it was purified by G-75 filtration (29,30). Subsequently, Jones et al. (41) further analyzed the mixtures and identified that several cockroach allergens of variable molecular weights were filtrated (G-150) in pool 1 and pool 2, not in low molecular pool 3. They studied the antigens and allergens of the individual pools as well as the crude extract mixture by means of crossed immunoelectrophoresis (CIE) and CRIE using cockroach allergic sera from Chicago. They reported that individual allergic serum identified distinctive allergens of different quantities and of quality from the cockroach extract. Most recently, Wilson et al. (42) reported interesting findings in Western blot analysis that individual whole body cockroach allergic sera identified variable numbers of different allergenic protein bands from individual extracts among the three cockroach species tested. This was a similar finding noted by Jones et al. (41). The noted variable allergen patterns were irrespective of the allergic subjects' geographic location between Lexington, KY, and Chicago, Il. Wilson et al. (42) identified, however, that there was a provable shared allergen among the three common species, approximate MW. 42 Kd., and a few distinctive species specific allergens from the American, German, and Oriental extracts.

Management of Cockroach Allergies

The best management possible for cockroach allergic patients is the avoidance of exposure. This can be done easily for the subjects whose exposure to cockroaches is limited to occupational encounters. In such a case, changing occupations would be the best way of managing cockroach allergies. However, atopic subjects who develop cockroach allergies from pest infestation in their dwellings and/or in the work environment, will have a more difficult time avoiding the causative agent. According to Raloff (5) and recent surveys of housing projects, the pest infestation seems to be increasing in spite of exterminatory efforts with new pesticides (4,5,7). Individual cleanliness and better cleaning habits seem to be helpful in controlling the infestation.

Immunotherapy was suggested for cockroach allergic subjects by Hellereich (15) for difficult cases, and was attempted by Marchand (21) on severe asthmatic subjects. Results were reportedly very encouraging. Kang et al. (43,44) reported that the cockroach immunotherapy resulted in significant reductions in symptom and medication scores of severe cockroach asthmatics. All steroid-dependent asthmatics became steroid independent (45). The noted improvement was even more significant for the subjects who had failed routine pollen immunotherapy prior to cockroach antigen therapy (37,45). The studies further reported that cockroach immunotherapy produced IgG type of blocking antibody in the serum as well as a decrease in cellular sensitivity of the treated cockroach asthmatics (43-45).

Summary

The omni presence of cockroaches makes cockroach allergies more prevalent than previously recognized. Massive domestic infestations produce indoor air contamination to the extent that cockroach allergens become an important airborne indoor allergen for patients with allergic airway diseases. The high prevalence rates of cockroach hypersensitivities among inner city asthmatics particularly increase its medical significance. Proper recognition and identification of cockroach allergies in the protean chronic human ailments are necessary to guide proper management of such cockroach-induced allergic diseases.

Pest control is the best way to manage cockroach allergic diseases. The afflicted individuals unable to avoid insect exposure may benefit by hyposensitization -- especially severe cockroach asthmatics. Allergen analysis and isolation of allergen(s) of the cockroach extracts are ongoing in an attempt to standardize the commercially available extract for diagnostic and therapeutic purposes.

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FIRE ANTS IN THE URBAN ENVIRONMENT

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ABSTRACT

Information on the impact and problems of the imported fire ant (<u>Solenopsis</u> <u>invicta</u> Buren) in urban environments is limited but the problem is perceived to be serious. It is essential that the density of the imported fire ant be considered when such information is obtained. The problem and its perception is a function of encounter rate, which is a function of ant density.

The basic problem in urban environments attributed to the imported fire ant does not differ substantially from that of rural environments. In the rural community imported fire ants are a pest of people, their homes, domestic animals, crops, pastures, and equipment. Similarly, in urban environments the imported fire ant is a pest of people, their homes, pets, gardens, lawns, and equipment. However, in urban areas pesticides are more likely over-used in attempts to manage imported fire ant problems.

Keywords - <u>Solenopsis</u> <u>invicta</u>, urban pest control

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INTRODUCTION

The genus <u>Solenopsis</u> contains a number of species that are called fire ants because of the sensation being burned with fire when several of these ants sting. <u>Solenopsis</u> are New World ants (MacKay and Vinson 1989) with several species native to the United States (Buren et al. 1974, Hung and Vinson 1978). Several of these native species occurring from the Carolinas across the southern United States to California, are considered pest ants (Hung et al. 1977), but in comparison to the imported fire ant (IFA) their densities are low and the problems they cause are minor. As the imported species have spread the native species have retreated (Hung and Vinson 1978). There are at least two imported species. The black imported fire ant, Solenopsis richteri, was accidentally introduced at the port of Mobile, Alabama around 1918. The red imported fire ant (RIFA), Solenopsis invicta, arrived some 20-25 years later in the same area. Soon after the arrival of the RIFA infestations began to occur in local communities from the Carolinas to Louisiana. However, even today infestations are not uniform and range from a few mounds to nearly a thousand per hectare.

Presently, the RIFA occupies over 971,000 square kilometers from the Carolinas across the southern states and half way across Texas. In some areas of their range a multiple queen (polygyne) form occurs (Miranda and Vinson 1982, Greenberg et al. 1985), with a higher nest density (Lammers 1987). The problems fire ants cause has been the subject of debate (Lofgren 1986) ranging from beneficial (Schmidt 1989, McDaniel and Sterling 1982) to detrimental (Apperson and Powell 1983, Vinson and Teer 1989). Much of the confusion can be attributed to poor documentation of the problems in relation to the density of the infestation. The lack of information has been particularly acute in the urban environment. Lemke and Kissam (1989) reported on a public survey of South Carolina residents in which 87% of the 430 respondents felt they had a severe RIFA problem. Without documentation as to the IFA density, it is difficult to ascertain whether one mound or hundreds constitute a severe problem.

There is little doubt that some people are impacted by IFA's. Shealy (1983) reported that the RIFA stung more people than bees, hornets, wasps and yellow jackets combined. Clemmer and Serfling (1973) reported that 28% of the individuals in 240 families surveyed by telephone in Louisiana were stung during the summer.

In this report I will examine areas of the urban environment impacted by the IFA drawing on the information from Lemke and Kissam (1989) and information from studies conducted in more rural environments.

THE URBAN ENVIRONMENT

Problems with IFA's in the urban community include those that are (A) direct (i.e., due to the ant) and those that are (B) indirect (i.e., due to problems associated with attempts to manage the ant). The direct problems can be divided into 4 areas of concern (Table 1).

In general, ants of any sort are considered a problem in urban environments when they occur in the "wrong" place. Many native ants and even exotic species that occur outside in small numbers are generally not of concern. However, any ant that invades the home or occurs in large numbers are considered a problem. The numbers make the ants visible and the movement of large numbers into a home represent an "invasion" that is usually met with immediate concern. In this regard, ants differ from many other urban insect problems, in which individual insects usually are encountered initially in small numbers. Exceptions occur in cases where ants cause damage, such as with carpenter ants. The urban dweller may not be aware of a carpenter ant problem until considerable damage has been done (Fowler 1986).

Fire ants also differ from many other insect pests in that they cause problems with plants, animals and people in both rural and urban environments. The IFA is unique in the urba environment because the ant is a problem in the home, lawn and garden, and impacts people, pets and equipment both inside and outside the home. Further the IFA differs not just because these ants sting, there are other stinging insects, but in the fact that these ants are aggressively recruited, can sting many times, and pustules form a day later which remain for several weeks that are reminders of the sting encounter.

TABLE 1 -- Problems in the urban environment attributed to the imported fire ant

A. <u>Direct</u>

1. Life threatening
2. Fear and deterrence of activities
3. Nuisance
4. Damage

   a) Vegetation
   b) Domestic animals
   c) Structures

B. <u>Indirect</u>

1. Pesticide over use
2. Ineffective products
3. Expense

LIFE THREATENING PROBLEMS

The venom of the fire ant is unique, consisting of cell killing alkaloids (disubstituted piperidines) and proteinacious allergenic components (Baer et al. 1977). A sting leads to a predictable response leading to a pustule which may persist for several weeks (Lockey 1974); however, between 1 to 5% of those stung exhibit symptoms of shock (Rhoades et al. 1977, Adams and Lofgren 1982) and deaths have been attributed to fire ant stings (Lockey 1979). Many people variously respond to ant stings with a systemic allergic reaction or secondary infections of pustules occur, both of which result in serious medical complications that are of genuine concern (Lofgren 1986). Paull (1987) estimated that 16% of those stung had to seek medical help. Pustules sometimes result in a discoloring and hardening or thickening of the skin resulting in a blemish that may persist for years (a cosmetic problem).

Lemke and Kissam (1989) reported that 89% of the respondents of their survey reported that someone in their family had been stung, but 31% of these respondents either suggested no reaction or a slight itch and red spot that only existed for a few hours. Such a reaction cannot be attributed to IFAs and indicate that other ants are involved. If only respondents having IFA problems were included the conclusions of the survey may have been much different. Therefore, it is important to document if the pest ants are Solenopsis and then to determine if they are native, imported, monogynous or polygynous ants. The difference provides an indication of the density which influences the perception of the problem. Native ants have densities of 10-25 mounds per hectare (Hung et al. 1977) and are infrequently encountered, as compared to over 900 mounds of the polygynous form of the RIFA per hectare (Lammers 1987), which greatly increases the encounter rate and perception of the problem. However, it is the multiple stings and constant irritation of the itching pustules which often become infected that provides a constant reminder of the encounter and creates a dislike or even a phobia for these ants.

FEAR AND DETERANCE OF ACTIVITIES

In the Lemke and Kissam (1989) survey, 34% of the respondents considered the RIFA a threat to their children and 5% reported they feared the ants. This creates a pressure to either eliminate the ants or avoid them. Elimination is difficult, leaving the alternative of avoiding the ants. The Lemke and Kissam (1989) survey indicated that 40% of the respondents altered their outdoor activities due to the ant. However, the percentage may be underestimated. Lemke and Kissam (1989) reported that there was a direct correlation between whether the IFA appeared to have increased or decreased their activity and the respondents change of habits. A majority (61%) of the respondents who reported the ant problem was worse reported they decreased their outdoor activity. This is significant, particularly if fire ant densities are taken into account.

The density of IFA in a particular area depends on a number of factors. One is the type of fire ant population infesting the area (native, monogynous, polygynous). Another is the environment, the ants being influenced by food sources and habitat. The third is whether the area is receiving a pesticide treatment. The fourth is the nature of the invasion. Some areas are heavily populated while others are not. Some of this may be due to the nature of the mating flights, but other factors may be operational. The problem is most severe in the suburban areas where fire ants are more common due to the presence of open land where queens can start new colonies. However, fire ants occur within the inner city, particularly in playgrounds and vacant lots or small yards.

The presence of high densities of fire ants make many activities difficult. Examples include: spreading a blanket on the ground for a picnic or sun bathing; leisure tending of a small garden; walking through the yard bare-foot or with sandals; or relaxing in a chair or bench in the yard. Children may be kept inside rather than risk being stung. The real impact of fire ants in deterring human activities is difficult to document. It is also difficult to determine the psychological and social effects of altering human activities. Yet, the threat of being stung and the implications certainly cause some shift towards more activities in artificial and protected environments.

NUISANCE

Documentation is difficult to obtain and largely unavailable, but at least some people adapt to the presence of fire ants through constant interaction of a few stings, avoidance and control. Of the 87% of the respondents that considered the RIFA a serious problem, 29% considered it a nuisance (Lemke and Kissam 1989). Again, density and whether controls are in effect is important. Some people have utilized present control tactics (Drees and Vinson 1989) and have been successful in the maintenance of fire ants at levels that some people may regarded as a nuisance.

DAMAGE

There is little documentation of types of damage caused by IFA in urban environments. However, types of damage caused by fire ants in urban environments probably do not differ from rural environments. Only details of the make-up of the environments differ; IFA's broadly cause the same problem in both. I have divided the types of damage caused by IFA's in urban environments (Table 1) into 3 areas:

<u>Vegetation</u>
Fire ants affect gardens, lawns and ornamentals. Problems in lawns are primarily the presence of mounds which are considered unsightly (8% of the respondents of the Lemke and Kissam [1989] study) and can interfere with mowing. The presence of mounds can damage mowers, as occurs with rural equipment (Lofgren 1986). Mowers may scatter defensive ants over the ground, equipment and operators. The mound area may collapse after insecticidal treatment leading to depressions in the lawn. In nutrient limited lawns the grass is often greener were mounds have recently occurred. Many of these conditions and problems are similar to turf farms, pastures, and golf greens (Lofgren 1986).

The major problem in ornamentals is the girdling of small trees and shrubs similar to what occurs with young citrus (Brown 1982). The cause of the girdling is not clear, but may involve attraction to sap (Lofgren 1986). Since IFA's are also known to damage new growth, young fruit, flowers and buds (Lofgren 1986) they could cause similar damage to various ornamentals. Such damage may depend on the ornamental species involved but such information is lacking. Fire ant resistant ornamental varieties may have a place in urban environments.

In flower and vegetable gardens, as well as in ornamentals, the IFA tends aphids and other homoptera which spread disease, and the IFA can protect these pests from parasites and predators (Vinson and Scarobrough 1989, 1990). What particular plants grown in the urban area that are most at risk to direct IFA attacks or to secondary problems due to the activities of the IFA is unknown.

In gardens, like crops grown in the agricultural community, the fire ant is looked upon as both beneficial and as a pest. Long et al. (1958)

and later researchers (Reagan 1981, McDaniel and Sterling 1982) reported on the importance of IFA's as predators and their role in controlling pests. The same phenomena occurs in vegetable gardens because IFA's are effective predators feeding primarily on other insects (Hays and Hays 1959, Wilson and Oliver 1969). However, IFAs attack beneficial insects (Nordlund 1990) which tarnishes their benefit and, as noted for ornamentals, the ants ability to tend homopterans may be a problem.

The IFA also causes serious direct plant damage (Lofgren 1986). Fire ants feed on the embryo of seeds, tunnel through roots and tubers, attack young fruit and tunnel in very ripe fruit (Drees et al. 1990, Lofgren 1986, Vinson unpublished). Crops reported affected include: corn, peanuts, sorghum, soybeans, peppers, okra, beans, irish and sweet potatoes, tomatoes, and cabbage (op. cit.). Many other plants may be affected in home vegetable gardens, but documentation is not available. The effects of fire ants on flower gardens is unknown but can be expected to be important.

Domestic Animals

Documentation of the impact of IFA's on domestic animals (pets) in urban environments (primarily dogs, cats, and rabbits) is largely not available, although 19% of the respondents in survey of Lemke and Kissam (1989) considered IFAs to be a threat to their pets. Even the impact of IFA's on domestic animals of agricultural importance (cattle, chickens, hogs) or wildlife is poorly documented (Lofgren 1986; Vinson and Teer 1990). However, from personal experience and observation along with discussion with several veterinarians the following can be offered. It is primarily animals kept "out of doors" that are at risk. Animals are also stung, they react as people do, and infections can occur. If free to move most are not seriously affected. Animals restrained in a small cage or by a leash may be subjected to more serious problems.

I have observed two distinct problems with pets, both of which involve the fact that IFA's are recruited to food and water (particularly during dry periods) and to areas of continual activity. When food or water is placed near IFA nests or is placed in the same location for a few days, ants by the hundreds are quickly recruited to the food dish or container. Their presence can either deter the animal from feeding (which can lead to slow starvation) and drinking (which can be detrimental in hot weather), or can badly sting an animal that attempts to do so. Stinging usually occurs around the mouth and nose or in the throat, which can lead to choking and suffocation due to swelling of the mouth, throat, and nose. Ants attack the eyes, which can lead to blindness. Fire ants may also attack other areas of the animal, particularly the anus and sores. The presence of ants continually attacking the animal when it tries to rest can result in exhaustion. Many of these problems can be reduced if the animal receives the proper care and attention.

Structures

The IFA usually exists in the soil but, is capable of nesting under various conditions if food and moisture are available, and homes can provide both. Like many ants, IFA's will forage into homes (Bruce et al. 1978) in search of food and moisture. They are often recruited to the kitchen, pantry, bathroom or places where pets are fed. Invasions are often sudden and dramatic due to the large numbers of ants. Yet, only 5% of the respondents in the survey of Lemke and Kissam (1989) considered ant invasion of the home a problem. This problem may be more serious in other regions of the country.

There are several conditions (based on personal observations) phone calls and letters that appear to cause colonies to move into homes. During floods when the ants are forced out of the ground and seek higher, dryer locations. IFA's colonies have been collected from wall voids, clothes piles in bathrooms, boxes of stored sweaters, under the carpets (including those of cars) and in a cotton stuffed chair. Such relocation of a large colony (several hundred thousand ants) can occur overnight. Discovery of such infestations usually comes as a shock to the resident and requires immediate attention.

Ants may invade homes during droughts, when the soil moisture is very low. During drought periods IFAs have been reported in bathrooms and kitchens, particularly if leaks or moist areas exist, as well as similar locations described above for ant invasion after floods. Moist areas around air conditioners are particularly susceptible to being invaded. Small colonies have also been collected in rain gutters full of leaves and debris from drought stressed trees, under shaded roof shingles and in the attic. In all the situations where IFAs move into homes they can cause damage through movement of soil into the nesting areas as well as chewing holes in the surrounding substrate. The fire ant is not a carpenter ant, but can cause minor wood damage. The effects of fire ants on electrical equipment is a more serious problem. Fire ants are attracted over short distances to electrical fields that occur in light sockets, electrical outlets, switches, relays and fuse boxes (MacKay et al. 1989; Vinson and MacKay 1990). They short out equipment resulting in its damage. The removal of insulation and shorting of equipment may also pose the potential for fires, although electrical fires caused by IFAs have not been documented. Electrical equipment within air conditioners placed outside the home are often damaged by fire ants due to easy access. Traffic control equipment, telephone junction boxes and electrical distribution equipment are often affected by fire ants. The ants bring in dirt which damages the equipment. They are attracted to contacts and relay switches which they enter and short. They also chew insulation from wires which then short circuit, particularly when moist conditions occur (MacKay et al. 1989).

INDIRECT PROBLEMS

The IFA is considered one of the major urban pest problems. IFAs comprise one of the major classes of calls to pest control companies and demand for their management results in a major proportion of the various pest control products offered to the public. Lemke and Kissam (1989) reported that 74% of the respondents to their survey applied something for IFA control. I am not going to discuss approaches to control, but will discuss some of the problems in their control and some of the problems that some present control approaches may pose.

Over 92 products are approved and marketed for IFA control (Drees and Vinson 1989). However, no matter what products are used, the effects are temporary and retreatment is necessary. The problem of IFA control is further compromised in suburban environments where a colony is located on one property but may forage and cause damage on another. A home owner or rentor wants rapid control provided by mound (nest) drenches, but mound drenches certainly will not eliminate the problem. Drenches control 80-95% of the mounds at best. Ants from nests that are not controlled, hidden nests, or nests that occur in locations where treatments do not reach (under cement walls or neighbor yards) continue to cause problems. The home owner is not satisfied and so retreats mounds again or utilizes other forms of treatment in an effort to eliminate the problem. In the survey of Lemke and Kissam (1989) 74% of the respondents applied pesticides of which 35% used a drench. Baits can control colonies that forage from a neighbor's yard and can control colonies unseen or in locations difficult to reach. For many home owners, the effect of a baits are slow-acting in some home owners either repeating the treatment or switching to something else before the bait has taken effect. Only 29% of the respondents of the South Carolina survey reported using baits (Lemke and Kissam 1989).

Regardless of which control methods are used, colonies often move after treatment. They often move into a neighbor's yard, and later return. This gives the home owner impression that the product worked. Wheather reinfestation occurs, the home owner uses the product again. A colony may move around a yard, resulting in several treatments being used on single colony. Finally, the fire ant is an effective invader and reinvasion generally occurs within 6 months to a year. The result of these problems is a heavy use of pesticides. The overuse of approved pesticides is not the only problem. Fifteen percent of the South Carolina survey respondents that used materials other than insecticides (Lemke and Kissam 1989) , 80% used gasoline; an extremely dangerous, environmentally damaging, and only marginally effective practice. Many people are convinced that various other products and devices will eliminate the problem. Most are ineffective and take advantage of people's fears and concerns. The use of various "home" remedies such as gasoline or pesticides that are no longer approved, cause serious pollution problems. Unfortunately, these home remidies are not really more effective than the approved products.

The urban environment presents challenges in the documentation of the extent of the problem, as well as challenges in pest management. Particular attention should be made as to the ant species involved and the density in any further studies to document the IFA's impact. We must develop safe and effective methods for the management of the IFA in urban environments.

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Presented Papers: COCKROACHES

Monoclonal Antibodies to Cocroach Allergen: Uses in Assaying Commercial Cockroach Extracts and House Dust Samples

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Laboratory Versus Field Performance of Baits for German Cockroach Control

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Comparative Toxicity of Bait Toxins and Bait Formulation Efficacy Against German Cockroaches, Blattella germanica (L.)

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Management of a Severe Infestation of Blattella germanica at Moss Side Market, Manchester England

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Ecological Biogeography of North American Cockroaches

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IGRs in Baits Fed to Late Instar German Cockroaches

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Identification, Purification and Quantitation of Cockroach Allergens Using Monoclonal Antibodies

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Monoclonal Antibodies to Cockroach Allergen: Uses in Assaying Commercial Cockroach Extracts and House Dust Samples

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We have raised murine monoclonal antibodies (mAb) to 2 major cockroach allergens, one cross-reacting among several genera (*Bla g* I) and one specific to the genus *Blatella* (*Bla g* II). A mAb based ELISA was used to screen housedust from 133 subjects (68 asthmatics, 65 controls) in Virginia, Delaware and Georgia and 6 commercial cockroach extracts. Measurable quantities of cockroach allergen was found in 46/133 homes. Highest quantities of allergen were found in kitchen dust (10^3-10^4 units/g) with lower quantities in dust from bedrooms and upholstered furniture (10-100 units/g). There was no significant difference between the mean levels of cockroach allergen in the homes of the asthmatic subjects relative to the homes of controls in the same geographic location. There was a difference between the number of asthmatic subjects and controls with elevated levels of serum IgE Ab (>40 RAST units) to CR and coincident elevated levels of CR allergen in their homes ($\geq$ 2 samples with $\geq$100 units/g) (9/22 asthmatics vs 1/16 controls). 6/6 commercial extracts assayed had detectable amounts of *Bla g* I (4.7-1,805 units/ml). Three of the "cockroach" extracts tested contained no detectable *Bla g* II. We conclude that cockroach exposure is common and kitchens are the primary site of cockroach distribution. In addition, it is possible that the diagnosis of cockroach allergy may be underestimated because of the inconsistent quality of extracts available for skin testing.

Laboratory Versus Field Performance of Baits for German Cockroach Control

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Tremendous differences have routinely been observed between the clinical activity of various bait formulations in laboratory trials and actual efficacy under field conditions. Much better performance is usually attained in simple laboratory exposure studies. Attempts have been made to explain these differences and to develop laboratory methodology that more reliably predicts performance under actual conditions of use.

Insecticidal baits tend to be very active in small arena tests. Acclimation before bait introduction does not normally dramatically reduce activity, nor does the presence of competitive food. The size of the test area and the complexity of the environment within the arena does affect results, reducing activity so that it more closely approaches results observed in the field. Results from larger and more complex arenas suggest that bait efficacy may be greatly affected by cockroach movement patterns. Because baits do not attract cockroaches over distance and satiated cockroaches have limited movement, consistent control is attained with more bait per area than would be indicated in small arena tests.

Twelve-chambered olfactometers and complex large arenas were used in laboratory tests to develop bait test results to correlate with previous field results. Complexity of the arena and dosage rates could be manipulated to approximate field results.

Learning and insecticide resistance may also affect results in the field. Very low levels of resistance to bait AI may result in population survivorship in instances where sublethal quantities of bait are consumed. This may be especially important in instances where multiple feeding bouts are required for kill. Associative learning may result in some cockroaches avoiding multiple, lethal ingestion of bait. Compared to a lab strain, significantly longer KT-100s were observed for field-collected cockroaches allowed intermittent exposure to bait, even though the measured resistance to AI was <5-fold (topical).

Comparative Toxicity of Bait Toxins and Bait Formulation Efficacy Against German Cockroaches, *Blattella germancia* (L.)

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Recent years have seen dramatic increases in the use of baiting strategies in the management of cockroach infestations. Baits have filled the need for treatment options in sensitive areas where liquid insecticide sprays represent too great a risk because of exposure or contamination concerns. The recent development of novel and highly effective bait toxins has further facilitated the widespread use of baits in cockroach management.

Bioassays with nymphal German cockroaches, *Blattella germancia* (L.), were conducted for four currently available bait toxins, and two toxins of historic significance: abamectin, chlorpyrifos, hydramethylnon, sulfluramid, chlordecone and mirex, respectively. Acetone solutions of AI, when mixed with ground lab chow and water, formed toxic diets of known concentrations. Dose-response studies were conducted and oral LD50s were estimated for each compound. Based on the mortality response following dietary exposures, the toxins were classified as either acutely toxic or causing delayed-mortality. Abamectin could be classified as an acute or delayed toxin, depending upon the exposure dosage.

The speed of kill from formulated cockroach baits, either commercial or consumer products, was also determined. During continuous exposure bioassays, the progression of mortality in nymphal *B. germancia* was recorded and LT50s were estimated. The speed of kill was found to be dependent on several factors: the toxicant, the concentration of AI, or the bait base.

Field trials determined the efficacy of new bait products in controlling infestations of *B. germancia* in multi-family, public housing units. In 1988, an aerosol-foam and a dry-dust formulation of abamectin bait were compared. Consumer bait stations, containing either abamectin, hydramethylnon or sulfluramid, were evaluated in 1989; additionally, a commercial paste formulation of sulfluramid was evaluated. Each of these cockroach baits provided acceptable reductions in visual estimated cockroach populations.

Based on the innate toxicities of the new bait toxins and the efficacy of current formulations, the successful integration of baiting strategies in cockroach management programs can be achieved.

Management of a Severe Infestation of Blattella germancia at Moss Side Market, Manchester England

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The Moss Side Centre in Manchester, England is a single structure of interconnected blocks containing some 400 apartments, a small shopping mall, a sports centre, and an indoor market. The centre is heated from a central boiler and heat is carried in hot water pipes inside service ducts. These ducts provide a network of connections between the blocks.

The market in Moss Side centre has 74 stalls selling everything from open food to stationery. In 1988 the market suffered from an extreme infestation of German cockroaches. Sticky trap monitoring revealed that 46% of the stalls were infested. Of these, 58% sold food. The mean number of cockroaches trapped in food stalls was 18.5 as opposed to 1.3 trapped in stalls which did not sell food. However, there was no direct relationship between cockroach numbers and the business carried on from a stall.

All stalls and the market premises themselves were treated using Deltamethrin liquid and Permethrin dust. Trapping immediately after treatment revealed excellent control.

In a number of stalls the electronic cash tills were also infested. Water or oil based chemicals and dust could not be used inside these machines without causing damage.

The possibility of driving the cockroaches out of the machines onto sticky traps using high temperatures combined with a low humidity was investigated. Laboratory experiments showed that 89% of cockroaches moved out of artificial harbourages within 24 hours at $40^{o}C \pm 2^{o}C$ and 17% RH compared with only 6% at $30^{o}C \pm 2^{o}C$ and 17% RH. The manufacturers of the cash registers concerned confirmed their machines would tolerate a temperature as high as $65^{o}C$. It is suggested that adverse environmental conditions such as high temperature and low humidity could be used to remove German cockroaches from sensitive electrical equipment.

Ecological Biogeography of North American Cockroaches

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Forty-eight native species of cockroaches are known from the continental U.S. Most are associated with moist, warm forest conditions. The greatest diversity of natives is found in Florida, followed by neighboring southeastern states with numbers of species decreasing rapidly to the north and west. A sizeable group of species of the family Polyphagidae (15 native species, 5 genera) are adapted to arid and semi-arid conditions and reach their greatest abundance in the southwestern U.S. The Great Plains, Rocky Mountain, and Great Basin regions have no native species. Native species can be divided into 4 groups based on distributions. The largest group (24 species) are associated with the humid neotropics, reaching their northern distributional limits in Florida, southeastern Texas, or the Gulf Coast. Another group (10 species) is associated with temperate regions of the eastern U.S., best represented in the southeastern states. Thirteen species are found in the southwestern U.S., mostly along the Mexican border. These are either dry-adapted species or are restricted to humid montane areas. Two species are found in humid temperate areas of the mountains of California, Oregon and Washington.

The distributional pattern of exotic cockroaches in the U.S. (21 species) is similar to that of native species in that the greatest number are found in warm, humid areas, especially in the Southeast, with fewer species in colder and drier parts of the country. An important difference is that all of the major pestiferous domiciliary and peridomestic species are exotic. Several of these have much wider distributions than any of the native species. New exotics are constantly being introduced and becoming established in different parts of the U.S. Most of the major pest species, including several which appear to be obligatorily domiciliary, were introduced into the country before the turn of the century. Recent introductions in contrast, seem to be more limited geographically, have narrower ecological tolerances, and appear to be less strongly associated with man-made structures and ecological disturbance. These differences are explained by changes in patterns of trade and transportation technology.

IGRs in Baits Fed to Late Instar German Cockroaches

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The effects of IGRs, both singly and in combination, in baits fed to late Instar German cockroaches were investigated. The bait consisted of 5 grams of pulverized dog food treated with varying amounts of IGRs. Fifteen male and fifteen female fifth instar nymphs were kept on the bait for 2 weeks. Reproduction was assessed by placing bait-fed individuals with untreated cockroaches of the opposite sex. Mortality, maturation, phenotype, and reproduction were recorded. Phenotype was classified as normal, divergent wing, curly wing, or nymphoid (larger than 6th instar and with enlarged wing buds).

Dosages for use in combination experiments were established from experiments on norval and fenoxycarb alone (the only effect of dimilin on reproduction was a slight reduction in hatch in 2 matings at 100 ppm). Double combinations ranged from 1ppm/each of two IGRs to 100 or 300 ppm/each material (norval + fenoxycarb; norval + dimilin; fenoxycarb + dimilin). The triple combination ranged from 1ppm 100 ppm of each IGR.

Hatch from phenotyically wild-type and most divergent wing individuals was normal. The first appearance of curly wings generally marked a sharp decrease in the number of productive matings. Nymphoids did not mate. Sterility of female nymphoids and many curly-wing females was associated with abnormal ovaries. Sterility in matings of curly-wing males was due either to failure to mate or to partial fertilization of oothecae.

The number of productive matings reflected the effects of mortality and sterility. Comparisons of productive matings in double combinations to those of fenoxycarb and norval alone were based on the total amount of IGR(s) present. Norval and fenoxycarb alone were equally or more effective than the double combinations in reducing the number of productive matings. Male sterility was incomplete at the highest dosages (1-2 productive matings at 300 ppm of norval and fenoxycarb; 1-3 productive at 200 ppm in double combinations). Complete female sterility occured at 60-100 ppm in the experiments with norval and fenoxycarb but not in the double combinations. The number of nymphs/egg case in productive matings did not differ significantly from that in the controls.

The triple combination was more effective than either double combinations or single treatment. Males at 300 ppm and females at 90 and 300 ppm were sterile. Hatch of normal phenotypes was significantly less than from normal phenotypes in the other experiments and the controls. Matings of normal phenotypes were frequently sterile (13 compared to 3-5 in the controls and other experiments).

Identification, Purification and Quantitation of Cockroach Allergens Using Monoclonal Antibodies

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We raised a panel of monoclonal antibodies (mAb) to German cockroach (Blatella germancia) which were selectively screened to identify IgE binding proteins using 28 sera from cockroach allergic patients. Four of these mAb (clones 10A6, 8F4, 3G12 and 1D4) detected allergens which were recognized by IgE antibodies in >80% of the sera tested. The allergens defined by mAb 10A6 and 8F4 have been provisionally designated as Bla g I and Bla g II, respectively. Two site ELISA assays were developed for each allergen using the MAb on the solid phase and polyclonal rabbit anti-cockroach antibodies to detect bound allergen. Comparison of the quantities of each allergen in extracts prepared from 14 cockroach species, showed that Bla g I was a cross-reacting allergen produced by Blatella, Periplaneta, Blatta, Supula, and Leucophea spp., whereas Bla g II was Blatella sp. specific. Bla g II was purified by mAb affinity chromatography and size exclusion HPLC. It showed a single band at 36kd on SDS-PAGE and a pI of 5.2-5.4 on analytical IEF. The source of the cockroach allergens was investigated by comparing Bla g I and Bla g II levels in body washes of live roaches. Allergen levels in "washes" ranged from 70-500 units/ml and 2,800-3,500 units/ml of Bla g I and Bla g II, respectively. The Bla g II levels were ~15 fold higher than those found in commercial skin test reagents. Our results show that mAb provide specific markers for the indentification and characterization of cockroach allergens and suggest that Bla g I and Bla g II are secreted and/or excreted products of German cockroaches.

SURVEY OF PESTICIDE USE, NEW ENGLAND, 1988/1989 FOR CONTROL OF BLATTELLA GERMANICA (L.)

The NE 166 Regional Project at the New Hampshire Experiment Station has implemented research in control options for the German cockroach, Blattella germanica (L.). During the years of 1988 and 1989 a series of 86 pest control operators throughout New England and New York State reported comparative usage and efficacy of standard cockroach insecticides and formulations in current cockroach management programs. Data was accumulated by completing a chart indicating usage and performance (Table 1). The data acquired in 1988 only gave usage without relative performance (Table 2), while data acquired in 1989 gave both usage and performance (Table 3). This project will continue for another 12 months with a final report and compilation in 1991. In 1990, 55 PCO's in Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, and Vermont were contacted (1989) to determine the comparative efficiency and usage of several insecticides in controlling the German cockroach Blattella germanica (L.). Results of these 1989 surveys indicate similar yet changing trends in cockroach insecticide control in New England. Results show that Chlorpyrifos is used by 83% of reporting PCO's with 74% indicating good to excellent control. The accompanying tables (2) and (3) will show the relative differences in overall usage and performance of 15 cockroach insecticides. The trend change from 1988 data indicates that the industry is substituting more (different) compounds into their cockroach control management programs. Hopefully this will help prevent a rapid rise of resistant German cockroaches in the northeastern states.

Compounds showing extensive use besides Chlorpyrifos are Cypermethrin (52% use, 90% good to excellent performance); bendiocarb (56% use, 39% good to excellent performance); boric acid (50% use, 61% good to excellent performance); pyrethrins (50% use, 64% good to excellent performance); Hydroprene (40% use, 68% good to excellent performance); Propoxur (40% use, 46% good to excellent performance); Propetamphos (29% use, 63% good to excellent performance); Cyfluthrin (18% use, 90% good to excellent performance); Fenvalerate (20% use, 64% good to excellent performance); Acephate (27% use, 74% good to excellent performance); Amidinohydrazone (36% use, 45% good to excellent performance).

Presented Papers: TERMITES

Factors Influencing the Tunneling Behavior of the Western Subterranean Termite, Reticulitermes hesperus Banks
J. L. Smith and M. K. Rust, University of California, Riverside, California 92521

Gulfport Field Research Medthods and Termiticide Efficacy Data
B. M. Kard, USDA Forest Service, Gulfport, Mississippi

Soil Sampling for Currently Registered Termiticides
J. Haskins and J. Jarratt, Mississippi Department of Agriculture and Commerce, Mississippi State, Mississippi

Field Evaluation of Disodium Octaborate Tetrahydrate as a bait toxicant against Heterotermes aureus
S. C. Jones, USDA Forest Service, Gulfport, Mississippi

Measuring Wood Consumption by Termites
D. A. Waller, C. G. Jones, and J. P. La Fage, Old Dominion University, Norfolk, Virginia

Acoustical Defection of Termites Inside Wood
V. R. Lewis, R. L. Lemaster, B. Dost, and F. Beall, university of California, Berkeley, California

Cuticular hydrocarbons: What do they tell us about termite biology?
M. I. Haverty and M. Page, USDA Forest Service, Berkeley, California

Termites of the United States: Recently described Taxa
M. S. Collins, Smithsonian Institution, Washington, D.C.

Factors Influencing the Tunneling Behavior of the Western Subterranean Termite, *Reticulitermes hesperus* Banks. **James L. Smith and Michael K. Rust, Department of Entomology, University of California, Riverside, CA 92521-0314**

Studies were carried out to look at the effects of abiotic and biotic factors on the tunneling behavior of the western subterranean termite *Reticulitermes hesperus* Banks. Tunneling rates increased as temperatures increased from 15-27°C. At 32°C, tunneling rates in the first 24 h were greatest (0.30 cm/h). However, this high temperature started to have negative effects on the tunneling rates within 48 h; resulting in termite mortality not observed at the lower temperatures.

Tunneling termites were allowed to encounter termites killed by exposure to termiticides and freezing. Termites killed by exposure to termiticides affected the tunneling behavior of *R. hesperus*. Termites continued tunneling after encountering freshly frozen termites. The effect on the tunneling behavior by termites which were killed and allowed to decay for various time periods was also examined.

Gulfport Field Research Methods and Termiticide Efficacy Data.
Bradford M. Kard, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, P.O. Box 2008 GMF, Gulfport, MS 39505

The pest control industry, chemical manufacturers, EPA, and private citizens and organizations depend on termiticide research data that are current. Therefore, up-to-date data from long-term field studies on the effectiveness of several termiticides are reported. Climate, soil type, and termite species differ among geographic locations; thus, efficacy data are provided for several field sites.

Selected chlorinated hydrocarbons, organophosphates, and pyrethroids are being evaluated for efficacy as soil termiticides at a range of concentrations. Data are reported for ground-board and concrete slab tests at sites in the continental United States and Panama; concrete slab-stake test results are reported for Midway Island.

The Environmental Protection Agency (EPA) requires efficacy data from USDA Forest Service field tests as one requisite in determining registration of soil termiticides. Data showing that a termiticide is 100% effective for a minimum of 5 years in at least three field sites generally are required. After efficacy data are collected, the manufacturer decides whether or not to apply for EPA registration, and, if successful, whether to market the product as a termiticide.

Since 1980, chlorpyrifos (Dursban^R TC), cypermethrin (Demon^R TC), endosulfan (Tiovel^R; Termiban^R), fenvalerate (Tribute^R), isofenphos (Pryfon^{R}6), and permethrin (Dragnet^R; Torpedo^R) have been registered as soil termiticides by the EPA for subterranean termite prevention and control. Except for endosulfan, all these termiticides have been marketed.

Until recently, chlordane and heptachlor were widely used for termite control, but in 1988 the use of these two chlorinated hydrocarbons was suspended pending completion of studies by the manufacturer. These termiticides provided 100% control of subterranean termites for 20 to 30 years or longer in the soil.

Recently registered soil termiticides (organophosphate and pyrethroid chemicals) generally have provided 100% control for the first 5 years and 80 to 100% control for years 6 through 10. When applied at similar concentrations, chlorinated hydrocarbon termiticides remained effective for longer periods of time than organophosphates and pyrethroids. Thus, the newer termiticides must be applied at the rates listed on the label if termite control is to be achieved. Generally, pyrethroids outlasted organophosphates under concrete slabs in the hot, dry climate of Arizona; and the reverse was true in other continental United States test sites.

Soil Sampling for Currently Registered Termiticides. **Jim Haskins, Division of Plant Industry, Mississippi Department of Agriculture and Commerce, Mississippi State University, P.O. Box 5207, Miss. State, MS 39762 and James Jarratt, Department of Entomology, Mississippi State University, P.O. Box 5446, Miss. State, MS 39762.**

The demise of chlordane has brought a new class of termiticides to the marketplace. These chemicals by the nature of their structure do not have the longevity that was seen with chlordane. In order to gain some experience with these products from a regulatory standpoint the Division of Plant Industry took a series of soil samples from recently treated structures during 1989. A standard sampling technique was utilized and all samples were analyzed by the pesticide unit of the Mississippi State Chemical Laboratory.

Analysis of these samples showed a wide range of results. They varied from non-detectable to 2,148 ppm. A handout of results will be available.

Field Evaluation of Disodium Octaborate Tetrahydrate as a Bait Toxicant Against Heterotermes aureus (Snyder). **Susan C. Jones, U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, P.O. Box 2008 GMF, Gulfport, MS 39505**

The desert subterranean termite Heterotermes aureus (Snyder) primarily occurs in the desert regions of southern Arizona and California, where it is a pest of considerable economic importance. Disodium ocataborate tetrahydrate (TIM-BOR[R]) was evaluated as a bait toxicant against this species in two field situations. In plots at the Santa Rita Experimental Range, ca. 40 km south of Tucson, Arizona, this chemical was evaluated against a colony in which base-line information had been obtained on the number of foragers (ca. 280,000) and territory size (ca. 2,200 m^2). Termite feeding behavior on treated fiberboard indicated that concentrations of 1.0% and 0.5% had some antifeedant properties. At ca. 6-month intervals, changes in the numbers of foragers were determined based on the mark-release-recapture technique, but the small numbers of dyed termites that generally were recaptured resulted in unreliable estimates. The recapture of dyed termites and studies of agonistic behavior indicated that termites did not emigrate from the treated plots. However, changes in territorial boundaries of surrounding colonies were observed. Inter-colony aggression in a field situation was observed for the first time in this species.

When baits were placed in a building at the Carl Hayden Bee Research Center, Tucson, Arizona, termites readily fed on fiberboard treated with 0.25% TIM-BOR[R]. Termites readily attacked baits placed on the floor and buried in the soil outside the building, but seldom attacked those baits attached to the walls or ceiling joists.

Measuring Wood Consumption by Termites. Deborah A. Waller, Department of Biological Sciences, Old Dominion University, Norfolk, VA 23529. Clive G. Jones, Institute of Ecosystem Studies, The New York Botanical Garden, Mary Flagler Cary Arboretum, Box AB, Millbrook, NY 12545. Jeffery P. La Fage, Department of Entomology, Louisiana State University, Baton Rouge, LA 70803.

Feeding preferences of xylophagous termites have been determined by comparing differences in wood biomass removed, percentage of wood consumed or visually rated damage. When test woods differ in physical characteristics such as density, these measures are not comparable. We examined the response of the Formosan termite, _Coptotermes formosanus_ Shiraki (Isoptera: Rhinotermitidae) to wood that differed in physical characteristics by compressing wood blocks to 40% greater than natural density. Termites ate significantly greater percentages, but similar amounts of biomass, of compressed over uncompressed pine, but significantly greater amounts of biomass, but similar percentages, of compressed over uncompressed mahogany. Whether percentage or amount of biomass removed should be used as a measure of preference depends on the insects' feeding patterns. If termites keep bite biomass constant, biomass consumed is the correct measure, while percentage removed is appropriate if they take bites of uniform volume on different substrates.

Acoustical Detection of Termites Inside Wood. **Vernard R. Lewis, Department of Entomological Sciences, University of California, Berkeley, CA 94720. Richard L. Lemaster, Bill Dost, and Frank Beall, University of California Forest Products Laboratory, 47th Street and Hoffman Blvd., Richmond, CA 94804.**

Acoustic emmission (AE) equipment was evaluated for its potential in detecting subterranean, dampwood, and drywood termites inside wood under laboratory conditions. Using video recorders, timers, and sensors sensitive to both audio and non-audio frequencies, the daily periodicity of termite behaviors and acoustic emissions were simultaneously recorded. The association of termite behaviors to acoustical emissions transmitted through wooden samples was significant. In addition, increasing the density of termites inside sample wooden blocks resulted in increased AE detected by sensors. The possible uses of AE equipment in the detection of termites within buildings under field conditions were also discussed.

Cuticular Hydrocarbons: What Do They Tell Us About Termite Biology.
Michael I. Haverty and Marion Page, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Berkeley, CA 94701.

Cuticular hydrocarbons (CHC) are part of the "wax" that occurs on the surface of insects. Hydrocarbons (HC) comprise about 90% of the material in insect waxes and are primarily responsible for prevention of desiccation. Hydrocarbon mixtures can be complex or simple: usually, insects have from 10 to 40 major components. It has been hypothesized that each insect species has a unique mixture of CHC. Thus it follows that CHC could be used as taxonomic characters.

For the most part we have been corroborating existing taxonomies that are based on morphological, genetic and/or behavioral characteristics. In the process we have identified sibling species and substantiated recent synonomies. Ideally, we should use CHC characters much like the classical taxonomists use morphology or behavior--sort groups of insects on the basis of CHC first, rather than use existing taxonomies and search for CHC characters.

The best example of the use of CHC as taxonomic characters is the study we initiated on the Pacific dampwood termites. Four consistent and distinct CHC phenotypes were identified from three species. A colleague was able to correlate three of the CHC phenotypes with a morphological character in all castes. We were also able to separate the morphologically similar CHC phenotypes with behavioral bioassays, and propose a new subspecies.

Another use of CHC is to relate similarities of CHC profiles to the origin of introductions of exotic insects such as the Formosan subterranean termite (FST). Has FST been introduced numerous times or, once introduced, has it spread via domestic or maritime commerce? Our assumption is that colonies with similar CHC profiles are likely to be more closely related (originating from the same geographical source) than those that are less similar. CHC components of workers were the same from the four populations we sampled. Quantitative differences in CHC components separate populations into different concentration profiles. Our results suggest that FST from Florida, New Orleans and Lake Charles are not related to those from Hawaii, and probably originated from other geographical locations. The population from Lake Charles is very different from those from New Orleans; FST was probably introduced into Louisiana from at least two separate sources.

Haverty (Continued)

Recently we have been identifying the CHC of western "species" of _Reticulitermes_. We have collected _Reticulitermes_ in California from areas known to have only _R. hesperus_ or _R. tibialis_, and found that their CHC profiles appear to be identical. Collections of "_R. tibialis_" from different locations in Arizona have provided different CHC profiles. There should be a significant effort to revise the genus _Reticulitermes_ in North America. This will require collaboration among the termite scientists within North America and would involve studies of morphology, behavior, genetics and, of course, cuticular hydrocarbons. Future species-specific control strategies will require accurate identification and an understanding of the foraging, feeding and interspecific behaviors of the species to be controlled.

Termites of the United States: Recently Described Taxa. **Margaret S. Collins, Department of Entomology, Smithsonian Institution, Washington, DC 20560**

Three new species and two subspecies have been added to the faunal list for the United States since 1970. Different techniques were involved in their recongnition, including surveys and morphological studies (2 species), karyotype analysis combined with biochemical and morphological studies (1 species), and combined morphological, biochemical and behavioral studies (designation of 2 subspecies). The roles these procedures played in establishing the new taxa will be discussed. Groups badly in need of further study using one or more of these procedures will be pointed out.

Biochemical studies of defense secretions give promise of providing greater insight into phylogenetic relationships in genus Amitermes. These studies involve biochemical analyses as well as behavioral observations.

Presented Papers: FLEAS

Calibrating the Gilmore Sprayer for Consumer Use in Flea Control

K. Palma and R. Meola, Department of Entomology, Texas A & M University, College Station, Texas 77843

The Effect of Formulation on the Activity of Pyrethroids Against Cat Fleas, Ctenocephalides felis

M. K. Rust, Department of Entomology, University of California, Riverside, California 92521

Comparison of the Ovicidal Effect of (s) Methoprene Against Ctenocephalides felis in vivo and in vitro

W. Donahue, Zoecon Corp., Dallas, Texas, R. Young, Young Veterinary Research, 7024 Carver Road, Modesto, California 95356 and R. Meola, Department of Entomology, Texas A & M University, College Station, Texas 77843

Adulticides for Cat Flea Control in Home Yards

R. Meola, Department of Entomology, Texas A & M University, College Station, Texas 77843

Calibrating the Gilmore™ Sprayer For Consumer Use in Flea Control

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The Gilmore™ hose sprayer is a popular means of dispensing outdoor chemicals by the consumer. In using this sprayer, consumers have questioned its accuracy in delivering the appropriate amount of chemical needed for outdoor treatments.

The purpose of this preliminary study was twofold: 1) to evaluate the accuracy of the Gilmore™ sprayer and 2) to determine the amount of variability inherent within these sprayers.

Six randomly selected Gilmore™ sprayers were used maintaining a constant orifice setting. Four hundred and fifty milliliters of water was placed in the sprayer reservoir. The sprayer was then used for a constant amount of time at varying outflow water pressures. The amount of water eliminated from the sprayer reservoir was noted. Three replicates were done for each sprayer.

There appears to be a correlation between the outflow pressure and the amount of water removed from the sprayer reservoir. There also appears to be differences between individual sprayers with regard to water output. The information found in this experiment may help develop a consumer guide in the form of a chart to aid in home calibration of the Gilmore™ sprayer.

The Effect of Formulation on the Activity of Pyrethroids Against Cat Fleas, *Ctenocephalides felis*

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Some of the second and third generation pyrethroids are beginning to make a major impact on urban pest management, especially for the control of ants, cockroaches, and termites. Previous studies have shown many of them, such as fulvalinate, permethrin, fenvalerate and tralomethrin, to be ineffectual against adult and larval cat fleas, especially when compared to the standard organophosphates, chlorpyrifos and propetamphos.

Problems associated with topically treating adults and interactions with various substrates may explain in part the poorer results with pyrethroids against fleas. Strips of filter paper treated with aqueous preparations of bifenthrin, cypermethrin and cyhalothrin WP were consistently more toxic than acetone deposits of technical material or EC formulations. The WP formulations were 10 to 100 times more active than similar deposits prepared with EC formulations. Microencapsulated formulations of permethrin, cypermethrin and bifenthrin did not improve their performance against adult cat fleas whereas microencapsulated chlorpyrifos and diazinon greatly extend their residual activity. The microencapsulated chlorpyrifos and diazinon did provide somewhat slower knockdown than did the EC formulations.

Many of the second and third generation pyrethroids are extremely active against adult fleas. However, when these WP formulations are applied to nylon carpet they lose their activity. Improved formulations and a better understanding of their interaction with various substrates is needed if we are to successfully utilize them in control programs against cat fleas.

POSTER PRESENTATIONS

Test Results of a German Cockroach Resistance Monitoring Program.

Brian C. Zeichner, U.S. Army Environmental Hygiene Agency, Entomol. Sci. Div., Aberdeen Proving Ground, MD 21010-5422

Atlas and Catalog of North American Cockroaches.

T. H. Atkinson, P. G. Koehler, Entomol. and Nematology Dept., Univ. Florida, Gainesville, FL 32611-0540

Structure-Infesting Anobiid Control Using Borates

D. A. Suomi and R. D. Akre. Department of Entomology, Washington State Univ., Pullman, WA 99164-6432

The Fire Ant Dispersion Patterns in Urban Habitats

A. P. Bhatkar, Department of Entomology, Texas A & M University, College Station, TX 77843-2475

Cockroach Incidence in English Hospitals and a Model Contract

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Insecticide Resistance Spectrum of German Cockroaches from Opelika, Alabama

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Test Results of a German Cockroach Resistance Monitoring Program

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Resistance testing was completed on 447 German cockroach, *Blattella germanica* (L.), strains collected from Army installations during the years 1973 through 1988. Most of the colonies (94 percent) were collected from the contiguous 48 states, and 74 percent were collected from food service facilities. Resistance ratios (RR) were determined using the jar test (time-knockdown response). Resistance ratios (RR_{50} and RR_{90}) were calculated as follows: RR_x = minutes for x percent of field strain to be knocked down (KT_x) divided by minutes for x percent of USDA Orlando normal strain to be knocked down. The mean RR_{50} was calculated for groups of 4 years. For the years 73 - 76, the mean RR_{50} was 1.2 for chlorpyrifos, 1.55 for diazinon, and 1.36 for propoxur. The mean RR_{50}'s for each of these chemicals increased for the years 77 - 80, and 81 - 84, until it reached a high for the years 85 - 88 of 1.75 for chlorpyrifos, 2.52 for diazinon, and 3.47 for propoxur. The median RR_{50} for bendiocarb was 15.9 for the strains collected from 1981 through 1987. Resistance levels to acephate and propetamphos were low for the years 1984 through 1988. The median RR_{90} was 1.6 for both of these chemicals. However, three (5.3 percent) of the colonies tested against acephate had RR_{90}'s $\geq$ 3; indicating that resistance was developing. The medium RR_{50}'s of strains collected from apartments were compared to those of strains collected from food service facilities. The medium RR_{50}'s for apartments were similar for chlorpyrifos and diazinon but greater for propoxur in the apartment-collected strains. This study documented an increase in resistance levels to chlorpyrifos, diazinon and propoxur over a 16-year period and found evidence of resistance development to acephate. Additional emphasis is needed on resistance management programs to control resistance development in this pest.

Atlas and Catalog of North American Cockroaches

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The most recent compilation of the taxonomy and distributions of North american cockroaches was made by Morgan Hebard in 1917 and included 46 native and exotic species. Since that time numerous species have been added to the fauna. Several native species have been described (5) or detected for the first time (8), especially in Florida and along the Mexican border. Another 11 exotic species have been introduced into the country since then. At least 2 species currently listed in the U.S. fauna probably do not occur here. There are 69 species of cockroaches in 31 genera in 5 families known from the continental United States, 21 of which have been introduced from other areas. Distributional patterns of genera and species are summarized. Ecological data for native and introduced species are analyzed, with emphasis on their association with man-made structures and ecological disturbance.

Structure-Infesting Anobiid Control Using Borates

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Control of structure-infesting anobiid beetles represents a formidable challenge to pest control operators (PCO's) in the Pacific Northwest. In Washington State alone wood replacement and chemical control costs for these insects exceed five million dollars annually. This represents a huge financial burden for homeowners.

Despite these enormous control costs, anobiids are little known. The major structure-infesting anobiid in the Pacific Northwest, *Hemicoelus gibbicollis* (LeConte), has never been studied. Yet the pest control industry continues to utilize chemical treatments to control this insect in spite of the fact that no basic biological data exist. It is also uncertain if these controls are effective.

As homeowners become more concerned about the use of organic pesticides within the home, a need is becoming apparent for compounds which are environmentally safe. Therefore, tests were conducted which utilized Tim-Bor (disodium octaborate tetrahydrate) as a remedial treatment for control of anobiid larvae within structural wood.

Larval activity and responses were documented by radiography. Concentrations of 10% and 20% Tim-Bor: water applied to point of runoff effectively killed 98% of larvae present. The effects of this material only became apparent after 3-4 months. However, this lag period should be of no real concern to either the PCO or the homeowner, since many beetle infestations are active for 20 years or longer. The long-lasting nature of borates should provide adequate control against structure-infesting anobiids for a number of years, certainly longer than conventionally used materials.

The Fire Ant Dispersion Patterns in Urban Habitats

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The dispersion patterns of single and multiple queen fire ant, *Solenopsis invicta* buren (Hymenoptera: Formicidae) in the southern urban habitats corresponds to those in the natural pasture habitats. The populations are so wide spread that the bioassays of myrmicides on field plots in either habitats do not generally meet the norms of statistical testing.

Cockroach Incidence in English Hospitals and a Model Contract

L. F. Baker
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English hospitals had a reputation of being institutions where the presence of cockroaches was considered the norm. It had become a commonplace belief that as the premises were old then the insects were self-generating! It was also believed that little could be done about them - apart from a temporary reduction in numbers as a result of a 'spot treatment'. A further factor which mitigated against better systems of pest control in National Health Service Hospitals was 'Crown Immunity'. This is an ancient British legal practice where it is not possible to enforce certain legislation on state owned ('Crown') premises or to prosecute for contravention.

What little data was available on the national incidence and distribution of cockroaches indicated that some 88% of hospitals were cockroach infested; and 12-13% of all hospital main kitchens had 'significant infestation'.

At the beginning of 1987 'Crown Immunity' was removed from the National Health Service in respect of Health & Safety and Food legislation. Prior to removal the Health Department issued a directive which required that "All District Health Authorities hsould adopt procedures to ensure that high standards of food hygiene and pest free conditions are maintained throughout their premises". Model administrative/management arrangements were also issued. In respect of pest control these were:

* All units should nominate an individual to have responsibility for pest control measures.
* The nominated individual should receive appropriate training.
* Pest Control work should be properly specified and contracted for.
* Contracts should conform to the Department's Model.
* Nominated officers should monitor contracts, undertake a planned programme of inspections, and submit quarterly reports to their General Manager.
* Advice on pest control was available to authorities free of charge.

Since the implementation of that guidance there have been in excess of four hundred nominated individuals' trained, the majority of hospitals are now using the 'model' pest control contract, and surveys of 219 hospitals show infestation rates as:

* Oriental cockroach only - 58.0%
* German cockroach only - 0.5%
* Mixed/Oriental & German - 4.5%
* Mixed/Oriental, German, & American- 0.5%
* Mixed/Oriental, German, & Banded - 0.5%

*Food Premises (Health Officers) - 9% "significant infestation"

PROGRAM

SUNDAY, FEBRUARY 25

7:30- 8:30 PM - Registration (lobby Adult Education Center)

8:00-10:00 PM - Mixer/Extension Information Exchange (Chesapeake Room)
Coordinator: K. Pinkston, Oklahoma State University

MONDAY, FEBRUARY 26

8:00 - Registration

8:30 - Introduction and Welcome — *AUDITORIUM*
- W. Robinson, Conference Chair

9:00 - Urban Entomology Perspectives
- J. Tucker, Entomol. Assoc.

C. Schal, Moderator

9:45 - Chemical Communication in Urban Insects
- W. Roelofs, Cornell Univ., Geneva

10:30 - *Break (Coffee in Lobby)*

11:00 - Indoor Air Pollution (Arnold Mallis Memorial Lecture)
- A. V. Nero, Jr., Univ. California, Berkeley

12:00 - *LUNCHEON - Guest Speaker: M. Potter, Orkin Pest Control*

1:15 - Insecticide Resistance Management — *AUDITORIUM*
- G. Georghiou, Univ. California, Riverside

2:15 - Adjourn to Paper Sessions
(Coffee available in the lobby)

2:30 - Concurrent Paper Sessions
- Termites - *Moderator: S. Jones* — *RM 0105*
- Cockroaches - *Moderator: B. Schneider* — *RM 2100*
- Fleas - *Moderator: R. Meola* — *RM 2110*

3:50 - Concurrent Discussion Sessions
- Termites - *Moderators: S. Jones, M. Chambers*
- Cockroaches - *Moderators: B. Schneider, A. Appel*
- Fleas - *Moderators: R. Meola, P. Koehler*

5:30 - Adjourn

TUESDAY, FEBRUARY 27

J. Paige, Moderator — *AUDITORIUM*

8:30 - Preventive Packaging for Stored Products Pests Management
- H. Highland, USDA

9:00 - Pharoah Ants
- J. Edwards, ADAS, England

9:30 - The Issue of Insecticide Repellency
- P. Zungoli, Clemson Univ.

10:00 - *Break (Coffee in the Lobby)*

10:30 - Concurrent Discussions
- Stored Products - *Moderators: H. Highland, D. Faustini, T. Granovsky* — *RM 2110*
- Pharaoh Ants - *Moderators: J. Edwards, S. Hedges* — *RM 0105*
- Repellency - *Moderators: P. Zungoli, D. Reierson, A. Frishman* — *RM 2100*

11:15 - Repeat of Concurrent Discussions

12:00 - *LUNCHEON - Guest Speaker: J. Edwards, ADAS, England*

1:00 - Begin Poster Session (Lobby Adult Education Center)

1:30 - Problems Associated with Evaluating Cockroach Control Chemicals
Panel: G. Bennett, J. Owens, R. Gold — *AUDITORIUM*

2:30 - Discussion

3:00 - *Break (Coffee in Lobby)*

L. Pinto, Moderator

3:30 - Formosan Termite Update
- N. Y. Su, Univ. Florida

4:00 - Penetration and Permanence of Wood Protection Chemicals
- W. Robinson, VPI & SU

6:00 - *Reception and cash bar* — *CHESAPEAKE RM*

7:00 - *BANQUET - Master of Ceremonies - Chris Christensen*

WEDNESDAY, FEBRUARY 28

J. Ballard, Moderator — *AUDITORIUM*

8:30 - Arthropod Allergens in the Urban Environment
- R. Brenner, USDA

9:15 - Impact of Cockroach Allergens on Humans
- B. Kang, Univ. Kentucky Medical Center

9:45 - Fire Ants in the Urban Environment
- B. Vinson, Texas A&M Univ.

10:30 - Closing Remarks
- W. Robinson, VPI & SU

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