Proceedings of the National Conference on Urban Entomology

1992

Compiled by: William H Robinson
Urban Pest Control Research Center
Department of Entomology
VPI&SU

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HISTORICAL PERSPECTIVE AND GOALS OF THE NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

In the spring of 1985 individuals representing urban entomology and the pest control industry came together to organize a national conference on urban entomology. They agreed the conference could open channels of communication and information exchange between scientists in industry, academia, and government, and foster interest and research in this important discipline of entomology.

The primary scope of the National Conference will be areas of urban entomology other than ornamental, stored products, medical and veterinary, and industrial pest control. Focus and emphasis will be given to innovation and research on household and structural insect pests. However, flexibility remains to include peripheral topics that pertain to the general discipline of urban entomology.

Leadership for the Conference will be provided by a Steering Committee composed primarily of representatives from academia, but including pest control professionals from industry and government. The 5-8 positions on the Committee will be selected from academia (4-5), industry (1-2), and government (0-1). These members of the Committee will serve a maximum of four Conference terms (8 years). New members of the Committee will be invited by the Chairperson to serve, after discussions on potential new members by the Steering Committee. The Committee will include two titled positions: Committee Chairperson, and Committee Treasurer.

> <u>Chairperson of Steering Committee</u>-The individual in this position will be selected from the existing Committee by the Committee members, and will serve one two-year term (one conference).

> <u>Committee Treasurer</u>-This individual will be selected from the Steering Committee and will serve a minimum of two terms (two conferences).

There will be an ad hoc Awards Subcommittee chaired by the immediate-past Chair of the Steering Committee. The remaining people on the committee will be appointed for a one-Conference term by the Subcommittee Chair. The Chair will report directly to the Steering Committee.

NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

1992 Planning Committee

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

Judy Bertholf
DowElanco
13355 Noel Rd
Dallas, TX 75240-6604

Roger E. Gold
Department of Entomology
Texas A & M University
College Station, TX 77843

John Paige
Ciba - GEIGY
Box 6430
Vero Beach, FL 32961 -6430

Art Appel
Department of Entomology
Auburn University
Auburn, AL 36849 - 5413

William H Robinson
Department of Entomology
Virginia Polytechnic Institute
and State University
Blacksburg, VA 24061 - 0319

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Western Exterminator Co.

TERMITOLOGY – A CAREER PERSPECTIVE

Frances M. Weesner
(Frances W. Lechleitner)

Department of Biology
Colorado State University
Fort Collins, Colorado 80523

INTRODUCTION

I wish to thank the Urban Entomologists for inviting me to these meetings and suggesting the wonderfully general title for this paper. I begin with three disclaimers: I am not a taxonomist (although I have certain thoughts about termite taxonomy); nor a person directly involved in pest control; nor, by training, an entomologist. I am just an invertebrate zoologist fascinated by the Isopterans and all the biological questions they pose. Although much information has been obtained regarding their biology in the past 50 years their tremendous diversity of habitat, structure, caste development, behavior, and so on, is just beginning to be appreciated.

THE DECADE OF THE MID-FORTIES TO MID-FIFTIES

In the mid forties I was fortunate to being working with the late Professor S. F. Light, in the Zoology Department of the University of California (Berkeley). He was working with groups of *Zootermopsis angusticollis* (Hagen), *Zootermopsis nevadensis* (Hagen) and *Incisitermes minor* (Banks). At that time these were all considered to be members of the Kalotermitidae. None of these possess a fontenelle. However *Zootermopsis* does possess multijointed cerci and lacks the ocelli present in kalotermitids. Some taxonomists consider *Zootermopsis* species as members of the Hodotermitidae, and in any case not members of the Kalotermitidae. Only three species of *Zootermopsis* are recognized, the third being *Zootermopsis laticeps* (Banks) which occurs in some areas of the desert southwest.

During the first eight months of 1946, Light and I observed the varied termite fauna of southern Arizona, primarily along the east face of the Huachuca mountains in Cochise County. To the neophyte it was astonishing to encounter the sheer numbers and the diversity of species present throughout the region. Maximum effort was expended collecting and culturing the Termitidae common in the area: *Amitermes wheeleri* (Banks), *Gnathamitermes perplexus* (Banks) and *Tenuiostritermes tenuirostris* (Desneux). Smaller settings were made of *Paraneotermes simplicornis* (Banks) and

Zootermopsis laticeps. *Incisitermes minor* and *Reticulitermes tibialis* (Banks) were also present. A trip northward to the Phoenix area provided collections of *Marginitermes hubbardi* (Banks) and *Heterotermes aureus* (Snyder) which were also maintained in culture groups. *Marginitermes* seemed to be a very favorable termite for laboratory study. Many cultures of most of these species accompanied us upon our return to Berkeley. I then accepted an appointment as Senior Laboratory Technician, and later had a joint appointment as Lecturer in Microscopic Technique, and later still as Lecturer in Zoology.

After the untimely death of S. F. Light, in 1947, Professor Ralph I. Smith was kind enough to oversee my graduate work. I returned to the Huachuca mountains during the summer of 1947, to further the earlier studies. Major studies in Berkeley concerned the development of young (incipient) colonies of *Reticulitermes hesperus* (Banks).

THE DECADE OF THE MID-FIFTIES TO MID-SIXTIES

In 1956, following my marriage to Dr. Robert R. Lechleitner, we moved to Fort Collins, Colorado, situated at about the 5000 foot level on the east face of the Rocky Mountains. A situation thought by many to be too arid and cold for termites. However, they are indeed present, and in many areas are very abundant. During this period I was occupied by activities surrounding two children, some writing, book editing, and, with the encouragement of the National Pest Control Association (particularly Dr. Ralph Heal and Dr. Philip Spear) engaged in what I generally call my "mail-order" research. This consisted of specimens and data from many Pest Control Operators and others interested in termites for one reason or another. During this time I also presented various lectures regarding termite biology to different groups.

THE DECADE OF THE MID-SIXTIES TO MID-SEVENTIES

In the late sixties I became a faculty member in Zoology at Colorado State University. During my initial years there I was busy writing lectures, etc., for two freshman courses in general Zoology and later for an upper division course in Heredity and Evolution. Termites, however, were never far from my thoughts, and a modest beginning was made by finding areas where the local species (*Reticulitermes tibialis*) was abundant. It was not until the mid-seventies that I really set about an intensive consideration of mature colonies of this species, both in the field and in laboratory cultures.

THE PERIOD FROM THE MID-SEVENTIES UNTIL THE PRESENT

The study of *R. tibialis* has mainly involved three areas: Bingham Hill, Rist Canyon and Poudre Canyon. All of these are situated in Larimer County, Colorado at about 5400 feet. In each instance a number of different foraging groups have been investigated, most of apparently distinct colonies. A few instances of multiple foraging sites for a single colony have been recognized by the release-recapture of individuals stained (in the laboratory) with Neutral Red. This was accomplished by feeding captured termites on wood soaked about 24 hours in a 0.5% aqueous solution of the dye. The wood was air dried and then utilized in preparing cultures for the termites. After two to three weeks termites which had picked up a substantial amount of dye were returned to the capture site. The usual number returned was 500 undifferentiated individuals. These were readily accepted by the "parent" groups. Obviously discretion needs to be utilized in introducing such dyed individuals into various groups in the field. It is doubtful that any valid conclusions regarding colony size can be drawn on the basis of release-recapture of dyed to undyed individuals. It should be noted that as many as 80,000 worker-line individuals were collected from several of the foraging sites over the years with no noticeable effect on the groups.

It became evident that there is a definite annual cycle of colony development, or at least groups at foraging sites. During the spring and summer there are various progressive stages of wing-padded individuals present, and the imagoes or alates appear in mid-September (as early as late August and as late as early October). Also evident was a seasonal production of new soldiers (as evidenced by the presence of presoldiers, or "soldier nymphs," or "white soldiers"). This most commonly was evident in late May and through June, July and August. It was also evident, year after year, and in different sites and in cultures that during the fall and early winter there was a lack of new soldier production, both in the field and in laboratory groups. This was true even in groups where the greatest numbers of foragers were captured during the fall. This must be kept in mind when considering groups set at different times of the year and maintained for limited periods of time (for example one or two months).

A few additional remarks should be made regarding the alate-line individuals. Mature alates produced in cultures in the late summer or early fall were cannibalized by other culture-group members after about one month of their presence. A very few penultimate individuals underwent a regressive molt to become neotenics; almost all alate-line immatures became neotenics (after a regressive molt - with respect to wing-pad development). Although alates were routinely cannibalized, neotenics were tolerated by the group in which they developed and any other group (same site or different site) into cultures of which they were introduced. It should also be noted the "worker-line" individuals were also capable of becoming neotenics although usually after a prolonged period in culture (as much as a year or more). Neotenics from the alate-line individuals usually developed in about one month. Further, the development (or presence) of a neotenic of one sex appears to hasten the production of a neotenic of the opposite sex.

With respect to soldier production it has been evident that some field colonies have a much greater soldier production than others (over several years) and this is evidenced by both field collections and laboratory culture groups. A series of experiments have been carried out with culture groups regarding soldier production. These include: removal of a new soldier and subsequent presoldiers from alternating cultures of different groups; removal of the first and all subsequent presoldiers from alternating cultures, and the setting of cultures with mature soldiers present in alternating cultures at the time of "take-down" and setting with the subsequent removal of new presoldiers in alternate groups, as they appeared. In considering the effects of each of these experimental groupings it is important to know the potential for soldier production for the subject colony and the time of the year during which such groups are set.

With respect to the "functional-workers" it has become evident that in *R. tibialis* the undifferentiated individuals continue to molt, even with an almost imperceptible increase in size, as long as they exist (which may be as long as three or more years). They are still capable of differentiation to presoldiers or neotenics even after a long period of time (as evidenced by the production of such individuals in cultures) and even without differentiation show a marked renewal of mandibular teeth at each molt. The continuation of molts is evidenced by the presence of premolt, molting, and callow (post molt) individuals in the cultures. I should state that I do not agree with the recent trend to characterize immature hemimetabolus insects as "larvae." From the time they hatch from the egg they display the general structure of the adult (even if apterous).

It should be noted that this is just a sampling of the data that have been obtained during this study. All of the information regarding the collections and the culture records has been computerized, it remains to me to complete it. It would have been impossible to census, examine, maintain, record and enter data without the assistance of some thirty persons over the years. To each of these I am most grateful.

EXPERT SYSTEMS AND DECISION MAKING FOR URBAN IPM

Nicholas D. Stone

Department of Entomology
Blacksburg, Virginia 24061

ABSTRACT Expert and knowledge-based systems ought to be important tools and products of any IPM research, teaching, and extension program. Currently in urban IPM, however, they are not. The importance of decision-oriented modeling and problem-solving methodologies is most evident when one looks at the definition of IPM. This paper distinguishes between pest management and pest control, the latter encompassing most of what people normally associate with IPM. Pest management is the process of making decisions, planning, and designing strategies for pest control. It is fundamentally based on decision making, and decision-based tools are well suited to improving the development of IPM systems. Knowledge-based systems make it possible to structure an IPM program around the pest control decisions that PCOs and homeowners make. The potential application of knowledge-based systems to various aspects of urban entomology is explored through some examples.

Keywords—Artificial Intelligence, IPM, Action Thresholds, Model, Database

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INTRODUCTION

Expert systems and the qualitative systems analysis techniques that underlie their development ought to be widely adopted in urban entomology, particularly in urban integrated pest management (IPM). In fact, however, urban entomology is one of the few applied disciplines in which the potential of expert systems has not been explored. This seems almost inexplicable, particularly since the urban pest control industry has the resources to purchase and use computers.

While this paper does not attempt to determine why these artificial intelligence (AI) technologies have not been discovered in urban IPM, it does offer an introduction to the subject and suggests ways in which expert systems and related AI techniques could be used to meet the needs of urban entomologists, especially in the area of urban IPM.

Some Definitions

This paper will be mainly descriptive, so I start with some definitions to introduce the subject of AI and its role in IPM and urban entomology. Defining terms in the AI field seems clearly justified, but definitions of IPM are needed as well. Too often, IPM is discussed as if everyone agrees about its definition while in fact there exist many different and vague uses of the term today. My definition of IPM is based on that of Smith and Reynolds (1966), but I also make a distinction between pest management and pest control (Stone and Schaub 1990, Plant and Stone 1991). This distinction is the basis for my argument that expert systems should play a key role in IPM.

AI and Expert Systems: Artificial intelligence is the science devoted to making computers behave intelligently (Winston 1984). At its core are the theoretical issues that relate to how knowledge is represented, how people think, how we infer new knowledge from information, how intelligent animals recognize objects in their environment, etc. The general public has become aware of artificial intelligence from movies like *2001: A Space Odyssey*, in which a computer carries on conversations with the crew of a space ship, from the intrusion of robots into automobile assembly lines, and from the recent cascade of "smart" bombs, planes, and tanks deployed by the US military.

Expert systems are another product of artificial intelligence and have been discussed widely in both computer journals and the popular press. Expert systems are computer programs that solve complex problems by mimicking the problem solving processes of human experts. In more general terms, they are a catch-all term for knowledge-based systems (KBS), computer programs that solve complex problems by relying on non-numerical problem solving methods. I prefer the term, KBS, because not all expert systems use knowledge gleaned from a single human expert. Most systems rely on multiple sources of knowledge, including textbooks, general theory, case histories, simulation models, and common sense knowledge.

In general, KBS have three components (Figure 1). There is a knowledge base, an inference engine, and a short-term memory. The knowledge base stores all the facts and knowledge the system understands about a particular problem area. If the KBS were a system to diagnose insect-vectored diseases, for example, the knowledge base would include: facts about which symptoms indicate the presence of specific diseases; what physiological conditions favor the outbreak of diseases symptoms; a set of disease control options, their health risks and what diseases they control; and rules for determining which control option might be appropriate in a particular circumstance.

The short-term memory of a KBS is used by the system to store facts and conclusions relating to a particular problem. When a user first runs a KBS, the short-term memory is empty. By responding to questions or by entering information, the user adds facts to the memory. When the KBS can use its knowledge to draw conclusions, these conclusions are added to the memory.

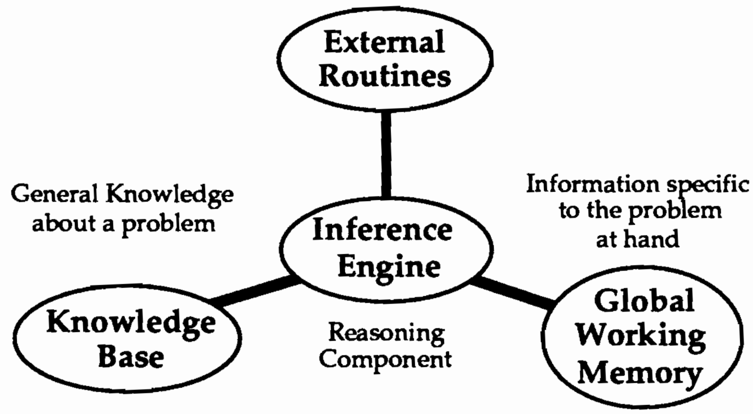

Figure 1. Three main components of a knowledge-based system or expert system, also showing the linkage to external routines. Note the separation of the inference engine (the intelligent component) from the knowledge it uses to draw inferences (From Stone 1989).

The system's ability to draw conclusions resides in the inference engine. This part of the KBS compares its knowledge about a problem in general (in the knowledge base) with what it knows about a specific problem (in short-term memory) and tries to make inferences and draw conclusions. Often an inference engine will keep a record of its reasoning, allowing the system to offer explanations to the user of how it reached a conclusion.

Finally, a KBS can use external routines (Figure 1) to augment its knowledge base and inferencing ability. For instance, it can run a simulation or perform a data query from a database. A whole class of KBS uses external monitors or probes to monitor how equipment is operating, for example. These external routines represent the linkage of KBS back to traditional computing applications.

Because a KBS represents knowledge as facts and rules, it can easily represent qualitative information or heuristic information, rather than just numerical and quantitative relationships and facts. These systems are also able to handle uncertain and missing information relatively easily. They explain their reasoning, so they are considered very user-friendly, and they function at the level of human experts. In fact they are often used to make scarce human expertise more generally available to others for training or to improve efficiency.

Pest Control *versus* Pest Management: To make it clear why a decision-oriented technology like KBS should play a prominent role in IPM, I go back to fundamental definitions and make a distinction between *control* and *management* (Stone and Schaub 1990, Plant and Stone 1991). Pest *control* describes activity leading to the reduction of pest numbers. The goal of pest control research is to eliminate the pest problem, and the research areas of pest control include a familiar list: improved chemical control, biological control, host-plant resistance (in agriculture), cultural control including sanitation, etc.

When most people refer to IPM research they are talking about pest control research. This is traditional, usually reductionist science. Biological and chemical research can lead to the discovery of new pest controls or to the improvement of existing controls. Pest control research has the capability to completely obviate the need for pest management when it is most successful.

Pest *management*, on the other hand, is based in decision making. It is needed because there exist persistent pests for which pest control methods have not been invented that control the pest with certainty. Pest management, therefore, is the process of choosing pest control options to further some overall goal or set of objectives. In agriculture, the overall goal is usually to maximize profit; in urban pest management, the overall goal may be to minimize client discomfort.

Pest management science is not traditional, reductionist science. It is highly applied and rarely leads to great theoretical breakthroughs. Pest management is a holistic science, looking at the whole system in an attempt to come up with coordinated strategies for pest control that are robust and effective.

IPM IN THEORY AND IN PRACTICE

This distinction between pest management and pest control is perfectly consistent with the definition of IPM from Smith and Reynolds (1966):

> A pest population management system that utilizes all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury.

IPM, they say, is a management system with an economic goal. IPM utilizes available pest control techniques rather than inventing new ones. The key issues in IPM center on the design of that management system: choosing appropriate pest control options; deciding when each control practice ought to be invoked; determining which practices are compatible and which are not and under what circumstances; designing a set of decision rules (e.g., economic and action thresholds) so that the system can be implemented. Obviously, a good IPM practitioner must have a sound understanding of the underlying biology of the control methods and the ecosystem, but that person's main concerns are decision making, planning, and design—not chemistry, physiology, and ethology.

Since IPM is an applied management science, it makes sense that management science techniques should be the foundation of IPM research. In fact, however, they are not. From the inception of the National IPM project of the 1970s and the CIPM project of the 1980s, a very narrow view of the management problem was advocated. Crop-pest systems were to be simulated using mathematical and numerical models, and optimal management strategies would then be discovered using systems analysis methods borrowed from engineering (Huffaker 1980, Frisbie and Adkisson 1986). Even though many benefits came from this promotion of simulation modeling, seldom did the simulation-optimization approach yield truly practical new IPM systems. Eventually, researchers began to recognize the failings of the approach, but only toward the very end of the national IPM projects (Getz and Gutierrez 1982, Getz 1986).

Choosing an Appropriate Management Science Approach

The simulation and optimization approach adopted by the national IPM programs in the 1970s and early 1980s was unfortunate in another respect. It absolutely required accurate and valid simulation models of agroecosystems before any optimization analysis could take place. This meant that often the primary emphasis of an IPM project was to develop a simulation model. Before the model could be used in an optimization scenario, however, it had to incorporate not only soil-plant-pest interactions, but also the economics of management. That, in turn, meant including the various effects of potential management practices and biological controls on the soil, plants, and pests (Figure 2). Naturally, these models could rapidly become overly complex. For systems involving more than a single pest, crop, or natural enemy the complexity increased exponentially. Even today, few if any models have achieved such completeness while remaining accurate and adaptive enough to be usefully compared with the real world. Needless to say, most modeling efforts remained at or near the center of Figure 2.

This emphasis on the model also drew attention away from the problem of IPM, focusing almost exclusively on the biology. While this discussion is based on crop production, the same danger exists in the urban setting. Consider that it is the homeowner or PCO who ultimately must implement an IPM program by making decisions. Figure 3a shows the kinds of information a PCO might consider when faced with a pest problem. Understanding the pest biology and the effectiveness of the range of control options available are clearly important, but just as important are issues like the amount of discomfort the homeowner is experiencing, the costs and prices of the product, legal restrictions, the homeowner's level of

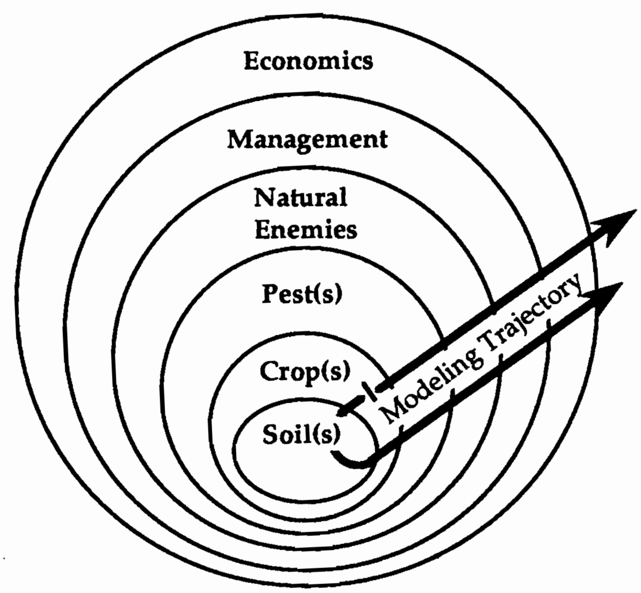

Figure 2. The classical approach to IPM research based on simulation modeling. Efforts are focused on the crop/soil/pest interactions, eventually expanding to include natural enemies, management, and economics (Modified from Stone 1989).

knowledge, health risks to the homeowner and the PCO, the need for future controls in relation to the PCO's schedule, and the PCO's social conscience. A true IPM system must address all these concerns, balance them, and help the PCO come to an appropriate decision. If the focus is skewed by an overdue emphasis on the biology and chemistry (Figure 3b), then the PCO will not be getting the help needed to make appropriate decisions.

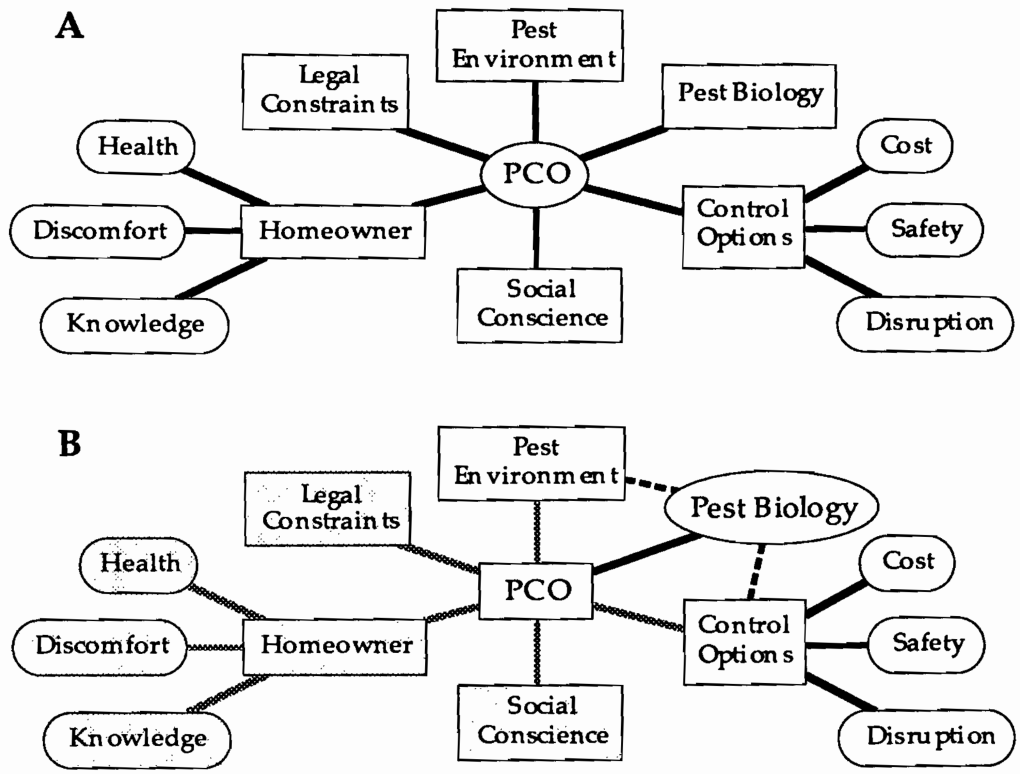

Figure 3. The PCO as integrator of information when making a pest management decision (*A*). Information flow creates a natural linkage between biological, environmental, and economic knowledge. In *B*, the focus on pest biology distorts the system. Pest management strategies based on a biological center often do not meet the needs of the decision maker.

A more appropriate organizational paradigm for IPM in agriculture and urban IPM would focus on the decisions that must be made (Stone 1989). First, identify the key decisions a PCO must make before recommending a pest control action, then build a model of the decision making process. This kind of decision model (Figure 4) shows the decisions, what information they depend on and what other decisions they influence. It also shows sources for information. By building this kind of model first, one can immediately see the relevance of biological information to an IPM decision, for example.

Following the development of a decision model, each decision node in the model is converted to a set of rules or a decision table. Because each node represents a well defined problem for which all inputs are specified, it should be relatively easy to build a knowledge-based system to represent the decision making heuristics for each node in the overall system. In the simplest cases, a computer system would not be necessary; the rules could be written in a handbook. For complex systems, a computerized expert system could be constructed.

An example: Aesthetic vs. Economic Thresholds

In researching this paper, I often heard that IPM in urban entomology is hampered by the fact that decisions are not made based on economic damage. The implicit assumption in this statement is that IPM in crop production is relatively easy to implement through the economic threshold. Ideally, one calculates the pest population density at which the pests' feeding damage produces an economic loss equal to the cost of a control action. When pest densities surpass this threshold, control should be initiated. In the urban setting, pests often do not cause economic damage, they cause discomfort. Using a similar threshold would require a homeowner to place dollar values on that feeling of unease. Such values would be highly subjective, would vary from one person to another, and would likely vary for an individual depending on other factors like the time of year, financial stresses, and habituation.

One alternative that has been suggested is the use of an aesthetic injury level as the basis for an urban IPM action threshold (Zungoli and Robinson 1984). A survey would be conducted to determine peoples' exposure to pests, their tolerance of pests at different population levels, and their financial evaluation of the discomfort or unease that pests are causing them. For groups of individuals or for people who live in particular kinds of housing, thresholds can then be developed that reflect the aesthetic values of the majority so that large-scale pest control strategies can be designed that will meet most peoples' needs. While this approach is attractive from a descriptive standpoint, it does not solve a PCO's problem when faced with a specific client. Just because the PCO knows that most people in the client's position feel a certain way does not mean that the client

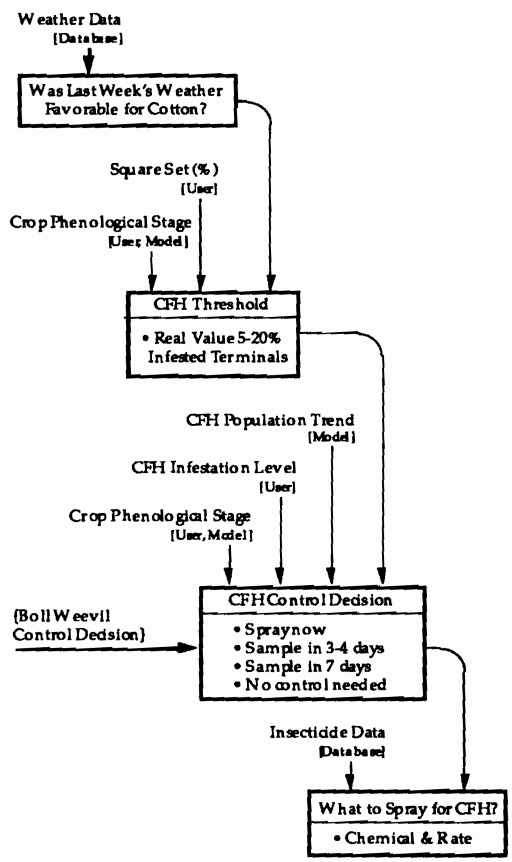

Figure 4. A decision model of a pest control decision for cotton fleahopper in cotton. Arrows indicate information flow; boxes are decisions. Unframed text indicates information and sources. Note that the CFH Control decision is also influenced by the decision about whether to spray an insecticide for boll weevil (from Stone et al. 1987).

is representative of the average and will agree.

Does this mean that urban IPM is impossible? Certainly not. What PCOs need is a management strategy that will allow them to make proper decisions. That strategy can be modeled as a decision model, which when fully fleshed out, provides PCOs with an objective methodology for making decisions. The same is true of the practical implementation of the economic threshold in crop production. It is not as simple as the ideal case described above. Figure 5a shows a signed directed graph model (digraph) for calculating an economic threshold. Once the threshold is determined, the control decision is trivial, but as shown in the figure, the threshold determination involves many factors that often vary through the season and from one field to the next. For example, in a field that was stressed early, the plants may not have the ability to compensate for damage later. This increases the value of plant material in the field and results in a lower economic injury level (EIL) than in the average field. Likewise, a field that is near to a source for natural enemies would be less likely than average to lose natural controls following an insecticide spray. Such a field would have a lower cost associated with control and thus a lower threshold. If all these interactions were encoded in a knowledge-based system that helped a farmer work through the EIL and ET calculations, the result would be a computerized IPM system.

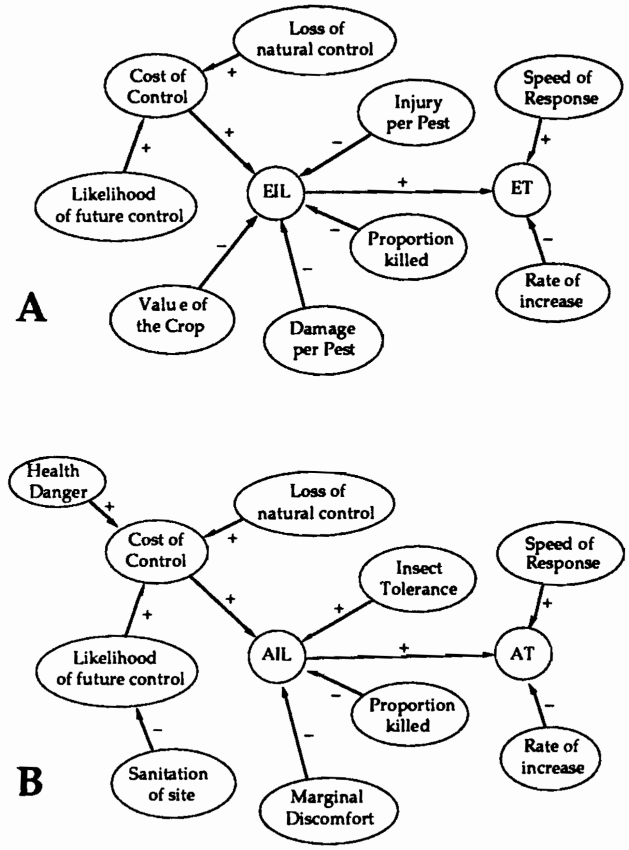

Figure 5. Signed digraphs of an economic threshold decision in a crop system (*A*) compared with an action threshold decision in an urban pest control situation (*B*). Arrows represent positive or negative influence of one node (oval) on another.

Implementing an aesthetic injury level (AIL) and action threshold (AT) could be done in the same way through a computerized management system. Figure 5b shows a digraph model of such a system. The decision that a PCO must make is very similar to the decision a farmer has to make to implement a truly dynamic ET. The PCO must decide whether the costs of a treatment, including the possible health risks are outweighed by the benefits to the homeowner.

CURRENT AND FUTURE ROLES OF EXPERT SYSTEMS IN URBAN IPM

Very little has been published about the use of expert systems in urban IPM. Carlos Rosario (1988) discussed using expert systems in a forecasting system designed to predict the likelihood of subterranean termite infestations in homes in Centre Co., Pennsylvania. Although the paper talked about the advantages of expert systems, the system as implemented by Rosario and Dr. Robert Snetsinger at Pennsylvania State University used a multiple regression analysis, not an inference mechanism to make its predictions (Snetsinger, pers. comm.). I have also been told that some urban pest management companies are using expert systems technology for in-house applications, but have not published their work for business reasons. Given the scant discussion in the literature, I will endeavor here to suggest problem types that are well suited to knowledge-based systems, giving examples from other disciplines when possible.

Potential Contributions of AI/Expert Systems

Prediction and Modeling: Many AI techniques, including rule-based expert systems, have been found to be useful in modeling. Of particular interest to urban entomologists might be the work simulating the behavior of insects in spatially heterogeneous environments (Makela et al. 1988, Stone 1990). These studies used observations about individual behaviors and their triggers to simulate population dynamics of insects and mites. Because the individual behaviors of many urban insect pests have been so well studied, and because the environments of these pests are structurally well defined in many cases, these modeling approaches could be extremely valuable.

Tactical Decision Making: Most expert systems to date have been developed either for diagnosis or prescription. These kinds of systems can help a user identify the cause of a problem and can recommend solutions. There are numerous examples in the agricultural and natural resource literature of such systems (see *AI Applications*, vol. 3 no. 3 for a bibliography as of 1989). In urban IPM, this kind of system could be used on-site by a PCO to help determine which control action to recommend. It could also be used by homeowners to diagnose a structural pest problem and to recommend a solution. Commercial retailers of pesticides could use such systems to help their customers choose appropriate products.

Species Identification: A special case of a diagnostic expert system is a species identification system. Obviously, identifying a pest is the first step in solving any pest problem. Again, several expert systems have been built for species identification (e.g., Woolley and Stone 1987), and there are also many non-AI computer programs for species identification that share many of the advantages of expert systems (e.g., Pankhurst 1984). These systems are particularly effective when combined with graphical images, providing much more information and assistance during the process of identification than a conventional dichotomous or tabular key. Again, both as an educational device for homeowners or as a field tool for PCOs, such systems could be very beneficial.

Training: Expert systems could be used as training devices, much in the same fashion as computerized flight simulators are used to train pilots. Computer programs could take PCOs or trainees through hypothetical client interactions, providing visual and textual clues about a pest problem and simulating the client's response to questions. The kinds of artificial intelligence programs well suited to building such systems include natural language understanding so that the trainee could talk in a natural way with the simulated client, case-based reasoning systems (Riesbeck and Schank 1989) which could quickly remind the trainee of similar cases and their solutions, rule-based systems like classical expert systems, and virtual reality systems that would effectively put the trainee into the simulated environment to let him or her explore visually as well as through questions.

Planning: Although most people think of IPM as a tactical level problem, developing an IPM system really involves long term planning. Also, managing a pest control company involves planning and scheduling problems similar to the prototypical 'traveling salesman' problem so commonplace in computer science textbooks. For example, a pest control company needs to schedule its employees' routes to maximize the number of clients serviced over time. This kind of problem is very hard to optimize, and various AI methods have been developed to achieve near optimal solutions in reasonable time frames. Planning and scheduling systems try to optimize the allocation of resources or the sequence of operations needed to carry out a task. Planning is currently a very active research area in artificial intelligence and AI planning systems have just begun to be developed in agriculture (Stone et al. 1992).

Intelligent Databases: Finally, the databases that scientists and pest control companies maintain can be enhanced by intelligent routines that automatically look for trends and patterns in the data. For example, an intelligent database of client records for a pest control company operating in a suburban area could automatically look for pest problems that are geographically localized and suggest locations at risk. These systems and their development have recently been reviewed by Parsaye et al. (1989).

CONCLUSIONS

Pest management is ultimately and intimately concerned with decision making, planning, and design. Knowledge-based systems provide both a framework for conceptually organizing pest management systems and a delivery system for disseminating decision support information. It makes sense from a research standpoint to use knowledge-based systems in IPM in the same way that biologists and ecologists have used mathematical models to help conceptualize and understand ecosystems. In addition, knowledge-based systems can be used to teach, train, and to deliver expertise.

Many tools used in developing expert systems are of more general academic interest in helping to solve decision-oriented problems, particularly decision making in the face of uncertainty and non-numerical constraints. Some of these have been reviewed or mentioned here. To advance the field of IPM as distinct from pest control, it will be necessary to train the next generation of IPM scientists in these qualitative and quantitative decision-oriented techniques.

Urban entomology is well behind other applied disciplines in looking at and adopting expert systems and related AI technology. This should change, not only in the area of pest management, but also in areas like PCO training and education, planning and scheduling, record keeping and analysis, and information dissemination. Ultimately, knowledge is the limiting resource, but even with perfect knowledge, perfect management is a very difficult prospect.

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RESEARCH DIRECTIONS - IMPACT OF THE PUBLIC AND POLITICS

Ronald J. Sbragia

DowElanco, 9002 Purdue Road, Indianapolis, IN 46268-1189

ABSTRACT

Public perception, and the political pressure that results directly from this perception, will have an ever increasing impact upon the research directions of the urban pest control industry. Many of the control methods currently being used today will continue to come under increased regulatory scrutiny in the current decade of the 1990's. A major reason for this is that urban pest control is increasingly being perceived as being of high risk to society. This perception is not due to the actual hazards associated with pest control practices, as they have been proven to be quite low. The high risks are more accurately based upon a term called the Outrage Factor which greatly increases the perceived risk in the eyes of the public. The future of our industry will be dependent upon how well we manage the impact of the Outrage Factor in risk evaluation. Three recommendations for managing this issue are first to deal with the concerns the customer have, not the ones we think they should have. Secondly, avoid memorable negative incidents that result in high outrage. Thirdly, work at building a higher level of trust within our customer base.

Keywords-public, perception, risk, hazard, Regulation Outrage Factor

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Good morning, it is a pleasure for me to be here today and discuss with you a possible vision of what the future may hold for the urban pest control industry. Predicting what will happen in the future is both easy and difficult. It's easy to make predictions but it's difficult to make accurate ones.

The fact that we're discussing the impact of the public and politics upon research directions truly represents a new paradigm of thought within our industry. When my career began in the discovery research area over twenty years ago, The factors that determined the direction of our research efforts were simple - The size of the target market plus the features, benefits and shortcomings of the competitive products serving that market. Product goals were also simple. We looked for products that filled an unmet need, offered a wider activity spectrum (or other performance advantages) or were more cost effective. Newer products displaced older products because they were better, more convenient to use, or offered more cost effectiveness. Fundamentally, this was a natural evolutionary process in the world of business.

What has happened since then? Certainly, some of the product goals we have historically defined still hold true, however, a number of other factors have begun to play an increasingly impactive role upon the directions our industry is taking.

I believe you can trace most of the significant changes that have occurred back to the fundamental premise that public perception leads to public and political pressure that leads, in turn, to political action which results in increased regulatory activity (Figure 1). The bottom line of this is that it is much more time consuming and expensive to bring new technology to the market today. On the other hand, the life cycles of many products have become much shorter due to regulatory restrictions. This results in a situation in which it becomes increasingly difficult to justify the expense associated with discovering new products - especially products targeted for urban markets. This presents an interesting dilemma. The demand for new technology continues to increase but the regulatory hurdles that keep us from meeting this demand are increasing at an even faster rate.

However, we're not here to talk about today, and we certainly cannot go back to yesterday. So let's talk about tomorrow.

We're not going to talk about all the specific regulations we have to deal with today or those we may have to deal with in the future. Instead, we need to decide what is over the hill from a broader perspective. Is it a straight road that leads directly to a more and more restrictive business environment or is it a branched road where we have a choice of direction?

Let me first discuss some of the possible consequences of continuing down the same road we have been traveling for the past several years. To best illustrate these consequences we will refer to them as the endangered species of the 90's. The endangered species I am referring to are not represented by plants, fish, birds, or other animals. These species are many of the tools and practices the urban pest control industry uses to provide a critically important service to society.

Endangered species are nothing new. We've always had them and some have gone on to extinction. For example, the chlorinated hydrocarbon insecticides are extinct in the U.S. and it probably will not be long before they disappear entirely.

It is an interesting analogy that when a living species becomes endangered, we enact laws and regulations to protect it. Within our industry the enaction of laws and regulations is what causes our species to become endangered and subsequently extinct.

One could argue whether extinction was good or bad. In the evolutionary process, extinction is an inevitable result of the inability of a species to adapt to an ever changing environment. Most extinctions have occurred as the result of natural forces. Within the business world I have mentioned that the replacement of a product or technology with newer and better products or technology is a natural evolutionary process. None of us, as manufacturers, like to see this happen when we are on the receiving end. We all do whatever we can to prevent the inevitable, however, the continual evolution of newer and better technology is an ongoing process. Sometimes you win and sometimes you lose, but that's what business is all about and we all have to be prepared to assume the risk. The challenge is what makes us better.

Why don't we take a look at what I specifically believe are some endangered species of the nineties (Figure 2). The first is more or less a carryover from the eighties and is the one way plastic container. While I'm certain that we would all agree that the disappearance of this species will be beneficial to society, the alternatives, however, pose very significant challenges that we must face. Formulating products that can be delivered in easily disposable or biodegradable packaging or in returnable containers increases the cost to the manufacturer, distributor, retailer, applicator, and ultimately the end user.

I would consider aerial application to be another endangered species. While we typically think of this as a crops related application method, there is a significant amount of aerial spraying of urban areas to control pests such as the Gypsy Moth. Anyone who follows legislative or regulatory issues cannot help but notice the ever growing concern over chemical trespass. Many people simply do not want their property treated either on purpose (through area treatment programs) or accidentally (due to spray drift).

Let's move a little closer to home. The yard for example. The application of granular products -especially insecticides - to turf is an endangered species. Some would also consider a related species, the application of sprays to turf to also be endangered. That doesn't leave much of an option for lawn care products does it? Although sprays are generally perceived as being more toxic to humans, the granular treatments are probably the most highly endangered because of their perceived greater risk of avian toxicity.

Let's get real close to home now and look in and around the house for some endangered species. Structural fumigation, used to eliminate damaging infestations of termites or other structural pests, should be added to the list. Due to the difficulty of pinpointing the location of the infestation, or in determining whether you have single or multiple infestation sites you have to treat the entire structure.

How about indoor broadcast treatments of insecticides for control of fleas or other pests. As the demand for reduced exposure to pesticides continues to escalate, species like this will continue to come under ever increasing regulatory pressure.

Let's look at one more endangered species. This is our old friend barrier termiticide treatment. This species has been around for a long time. The technology is archaic. It's labor intensive and requires relatively high rates of product to guarantee control. However, like many of the speçies we've talked about today its survivability has been dependent upon our inability to discover and market new paradigms of technology.

Overall, you might say that the danger we face today in adapting to an ever stricter regulatory environment is that as an industry we have not evolved new technology fast enough to keep pace with the rate of change in society's demands.

Before moving on, let's summarize a few fundamental concepts that are the major contributors to the endangered status of these species.

I believe there are three primary factors that have given rise to most of the concerns we see today. The first is the issue of recyclability. The concept of using something once and throwing it away is easily criticized as a wasteful expenditure of resources. The second is the use of broadcast applications. Since pest infestations are typically sporadic, broadcast treatments imply application to areas where the problem does not exist. This results in the perception of increased and unnecessary exposure. The third factor revolves around the use of preventive programs. To many, preventive programs imply indiscriminate use of pesticides and thus an unnecessary level of exposure. If you look back, every example of an endangered species is characterized by one or more of these factors.

What is the end result here? It's a interesting dilemma that after decades of waging war against urban pests, we find ourselves in a position where the pest species are not endangered, but the methods used to control them are. How did we ever get in this position?

We all see ourselves as a beleaguered industry, adrift in a sea of legislative and regulatory issues. Pressures continue to build for more and more regulation of what we do and how we do it. The perception of the urban pest control industry continues to move from one of providing a tremendous benefit to mankind and society to one of being a necessary evil. We see more and more offerings of alternative pest control methods that play off the fears and concerns of the public relative to the use of pesticides. Whether these are effective or not doesn't matter as long as they are not "toxic".

We all typically stand around scratching our collective heads trying to figure out what to do next, or how to deal with the latest round of issues or regulations that get thrown our way. We all, however, agree on one thing. We have seen the enemy and it is those environmentalists and those regulators, right?

Wrong! In the first place, calling the various special interest groups environmentalists is giving them credit they do not deserve. Secondly, we must realize that people in regulatory agencies are simply fulfilling the job they have been told to do. We need to focus less upon what they are doing and more upon why they are being asked to do it. What I would like to propose is that we adopt a more accurate view that says we have seen the enemy and it is us.

Now I fully realize that there is a segment of the population that is always going to be opposed to any kind of technology no matter what we do. And I also realize that the scorecard for regulatory agencies is, by definition, going to be based upon what practices they regulate not what they enable. However, even with all this, I would suggest that if you want to stop someone from taking potshots at you the first thing you should do is stop supplying them with ammunition.

One of our problems, as an industry, is that we do not give proper weight to the impact of what most of us might consider minor problems. We sit there and wonder why there is so much furor over products or practices that we consider to truly be of low risk to the customer and to society, so we typically do little in response to these problems. We therefore wind up being perceived as an industry that is slow to respond to the concerns of the public. Why is that?

I firmly believe that just as there are some fundamental laws of nature that regulate life and survival on the planet, so are there laws and principles that have guided our behavior to where it is today. Let's discuss some of these.

Let's refer back to the first example of an endangered species that I mentioned - the one way plastic container. We'll start here because this is an example of a species whose demise would be seen as generally beneficial. You might ask two questions. First why hasn't the desired evolutionary process allowed this species to become extinct? Second, why is this container issue causing such a problem? I believe the problem here lies with two impactive but conflicting forces. The first is what I call the Principle of Limited Good Intentions, and it states:

> Most people want to do the right thing (as long as it doesn't cost them any money).

What this means within much of the industry is that returnable containers are great - as long as the extra costs are balanced by savings in container disposal costs. It means that premeasured dosages in water soluble bags are great - if they offset the increased risk or cost of improper measuring.

The second force is what I will refer to as the Law of Business Evolution and it reads:

> The rate of evolution is proportional to the external pressure being applied.

There is probably a very typical sequence of events that occur within the manufacturing community in dealing with directives that come from external sources - typically regulatory bodies. For example, we know that FIFRA 88, Section 19 will result in the phasing in of many regulations that will attempt to stimulate the adoption of recycling programs for containers. Regulations like this typically set in motion what I call the Crisis Continuum (Figure 3).

When industry becomes aware of what is coming down the road, a typical response is to say to ourselves that since this is coming we can get a jump on the issue. We then start planning some actions that will result in products that comply with the proposed regulations. These plans are then carried to the next or action phase where you actually begin doing the work of developing the technology and the strategies for introduction. The technology or product is then launched, typically at a higher end user cost than the older technology. The reality phase sets in when you fail to reach your sales goals. Typically this results directly from erroneous information derived from your market research program. The information is erroneous because the act of telling a market researcher you're willing to spend more money is usually very different than actually taking money out of your wallet to do it. While there are always progressive individuals and businesses who see the value of your new technology and become satisfied customers, economic realities and the fact that the actual regulations have not been implemented yet, limit the adoption process. What occurs next is a kind of limbo until a deadline is approached. This is when we enter the crisis phase and a flurry of activity ensues to come under compliance - which is finally achieved although deadlines typically have to be extended.

If you take a broader view of business in this country, you might say that this process has become ingrained in our society. We are very good at crisis management. when we need to we can achieve results in a hurry. We have, however, lost our position of leadership in the development of new technology. We respond to challenges. We respond to the development of new technology elsewhere. The danger of the Crisis Continuum is that it fosters an attitude of not needing or wanting to do anything until we have to. If it ain't broke don't fix it.

Hopefully this is changing. The movement toward quality improvement is becoming very visible. We see much more proactivity versus reactivity in our approach to business. More and more companies are adopting quality programs. And so must it be within the urban pest control industry. We must change our attitude. We must take the position that the road to business success is based upon being a supplier of the highest quality products and services, as well as being more attuned to the concerns of the customer. We must successfully adopt a proactive move towards quality improvement within our industry. Only then will we be successful in pre-empting regulatory action and in taking the crisis out of this process.

Obviously this is easier said than done. New technology or approaches to the business do not come up that often. Even when they do, they may be relatively slow in being adopted. This results from what I call the Catch 22 Principle:

> Progressive businesses that adopt new technology or practices that are beneficial to society are often initially placed in a position of strategic disadvantage.

This can be an issue all the way through the distribution channel. Does this sound familiar? A manufacturer changes a label to provide stricter application requirements. This could be due to a desire to reduce exposure to the product for stewardship reasons. Would this be viewed by the industry as a good move or would competitive manufacturers tout this as a benefit for their product? Would some PCO's switch to a less effective product because they did not want to be inconvenienced and increase the time on the job?

Another example, when a pest control firm says they are going to hire only top quality technicians, provide them with in depth training, and make a long term commitment to them as employees, they are betting that the short term impact of higher costs will pay off in the long run by developing a more professional image and reducing callbacks and turnovers.

In the end, quality will always win out. Our challenge is to understand that while fundamental laws of business and competition operate in our industry, society has a limited understanding of what we do, so it's impression of us is build primarily upon perception. Unfortunately, those who fail in our industry because of a poor quality of products and services also leave behind a legacy of poor perception of us within society. Let's talk more about this word perception.

In physics, the Law of Conservation of Energy tells us that all energy in the universe is constant. It may only be converted form one form to another. We have a similar law in business which I will call the Law of Conservation of Business Prosperity, and it reads:

> In most markets, total prosperity is constant. It may only be shifted from one entity to another.

This is perhaps more clearly demonstrated by the graphic example shown (Figure 4). This example shows that due to some particular action, A loses and B wins. This is a fact of life in a competitive environment. For most industries, this model will suffice. In actuality, however, a more accurate representation of this for our industry is shown here in which P stands for Perception (Figure 5). The delta, or action, has a strong impact upon the resulting perception. If B wins because of the introduction of newer, better technology then the end use customer is happy and the public will perceive this as positive. On the other hand, if B wins because of regulatory action taken against A, the customers may also be unhappy and the industry will suffer another black eye because they will be perceived as having offered products that are unsafe or are detrimental to the environment.

The numerous repetitions of this process over the past years have lead us to where we are today. That is that pest control is increasingly being perceived as a high risk industry.

Why this is true leads up to the final point I wish to make today. We've tried to take a somewhat lighthearted approach to some of the principles expressed earlier, but now it's time to get serious. Let's discuss what I will call the Societal Risk Perception Model. This model, and especially how we deal with this model, will ultimately determine the fate of the endangered species I mentioned earlier. It will also determine how much additional pressures will be placed upon our industry. My Societal Risk Perception Model is composed of three simple equations (Figure 6).

Equation one is perception equals reality. We all have to clearly understand this equation. It is a fundamental fact that within society, or within ourselves as individuals, what is perceived to be true is true. Reality is in the eye of the beholder.

Equation two says that risk is proportional to hazard. This too is fundamental. No one will doubt the fact that under a given set of circumstances, the relative risk of a number of options will be proportional to their relative hazards. The risk of getting in an accident on icy roads is greater than the risk on dry roads because icy roads result in more hazardous driving conditions.

Equation three is the most important of the model. It says that perceived risk is proportional to the hazard plus a term called the outrage factor. I first heard this concept presented a few years ago by Dr. Peter Sandman, Professor Of Environmental Journalism at Rutgers University and it has had a profound effect upon my understanding of the dynamics of what is occurring today.

This equation really says that the perceived risk (remember equation one tells us that society will view it as the real risk) will actually be more dependent upon the outrage factor rather than the hazard. The hazard is constant. It can be measured. If outrage is high the perceived risk is high. If outrage is low the perceived risk is low.

The fundamental difference we have to learn to deal with is that professionals measure risk using equation two, while everyone else uses equation three. By everyone else I mean the public, which includes our customers. Equation three also tells us that the public will underestimate the risk when outrage is low but will overestimate the risk when outrage is high.

Our problem, ladies and gentlemen, is that within our industry the perceived risk is great because the outrage factor is high.

What are some of the factors that determine whether the outrage factor is high or low? There are several, but I will focus on the most important (Figure 7).

The first is voluntary versus involuntary. Think of the furor over secondary cigarette smoke. It is a much more controversial issue than smoking. Even though the cancer risk is orders of magnitude lower, the involuntary aspect results in a very high outrage factor. Now think about aerial spraying of a residential area for gypsy moth. Typically, this is involuntary and therefore of high outrage. What about you having your lawn and garden sprayed for pests? This is voluntary for you, but involuntary for your neighbor.

A second variable is whether the action is familiar versus unfamiliar. We've all heard the saying that familiarity breeds contempt. This is the dreaded enemy of safety programs in any company. Accident after accident can be traced back to familiarity in any procedure leading to a reduction in the risk awareness of the associated hazards.

A third variable relates to whether an event was not memorable versus being memorable. This refers to our remembrances of something gone wrong. To many, the 55 gallon drum is a symbol of risk. This is typically due to the fact that we all remember the myriad of stories on hazardous or toxic waste sites showing drums as the storage container.

Whether the event is controlled by the individual or controlled by someone else is a fourth variable. Ask yourselves if you feel safer driving a car or being a passenger. Most people feel safer driving because they are in control.

Number five refers to whether your activity is fair versus being unfair. What we primarily refer to here is the distribution of risks and benefits. For example, if you want to build a manufacturing plant in a small town, jobs and revenue would be an obvious benefit. The hazards associated with the resulting increased traffic might be perceived as a fair tradeoff, whereas the risk of polluting the local environment would be much more unfair and therefore of much higher outrage.

A final variable refers to the level of trust. Are you trustworthy or untrustworthy? The impact of this is clearly obvious. Perhaps surprisingly, one of the simplest things you can do to increase trust is to deliver appropriate warnings.

Of these six variables, those dealing with the voluntary, control and trust aspects are typically the most important.

The implications of this concept are very straightforward. When the public evaluates risk it looks at the outrage factor not the actual hazard. Industry has spend countless millions of dollars trying to educate the public on relative risks and hazards with little success. I can provide you with stacks of credible scientific data showing the risks associated with pesticide use are essentially negligible. These data, however, are of little use as long as the outrage factor continues to be high.

What does all this mean to us? Is there a way to tie this all together so we can learn from the past to help us pick the right branch of the road to the future? Can we do anything to save the endangered species of the 90's? Can we keep from adding to the list?

Most certainly, we can expect that the public and politics will have an ever increasing impact upon the directions of research in this country, as well as the way we do business. If we are going to continue to spend ever escalating billions of dollars on regulations targeted at protecting us from unmeasurably small risks, the future of our industry and, in fact, this country as a competitive force in a world economy is increasingly bleak.

The only thing that can help us change the path we have been following is public opinion. Make no mistake about it, we are in a battle for public opinion. We are in a tug of war with powerful special interest groups and we are both trying to move public opinion to our side. Frankly, we have not been doing a very good job of this. The question is, how can we do better?

Let's go back to our roadmap to regulatory action. We have historically tried to short circuit this process by trying to lobby against political action being taken against us (Figure 8). Even though we are sometimes successful, we do little to change the perception and the result is typically little more than a delaying action.

We would be much more effective if we could impact the perception that initiates the process (Figure 9). This would clearly be a huge task and most probably lies outside of the circle of influence of any individual, or probably any company.

There is, however, a more accurate roadmap to regulatory action that we all can impact as individuals. Public perception is the sum of all the plusses and minuses of individual perceptions. The only way we will ever gain an overall positive public perception is to do an effective job of increasing the positives and decreasing the negatives. This, I repeat, will be dependent upon how well we manage the outrage factor in risk evaluation (Figure 10).

There are many ways in which we can effectively manage this, but I will leave you with three suggestions. First, understand the needs and concerns of the customer and satisfy them. Deal with the concerns they have not the ones you think they should have. Second, avoid memorable incidents. These result in high outrage and lead directly to regulatory action. The impact of a negative incident that gets reported in the press is multiplied by a factor of thousands. In our business, not taking the time to do the job correctly is inexcusable. The third point is to build trust. Our trust bank account in the eyes of the public is considerably lower than it should be. Remember that giving warnings builds trusts whereas unexpected surprises destroy it.

In conclusion, I would like to thank you for letting me share these thoughts with you today. I hope the time has been useful to you with regard to perhaps taking a slightly different view of how we might deal with public and political issues in the future. Unquestionably, the challenge we face is huge, but as I said before it's the challenge that makes us better.

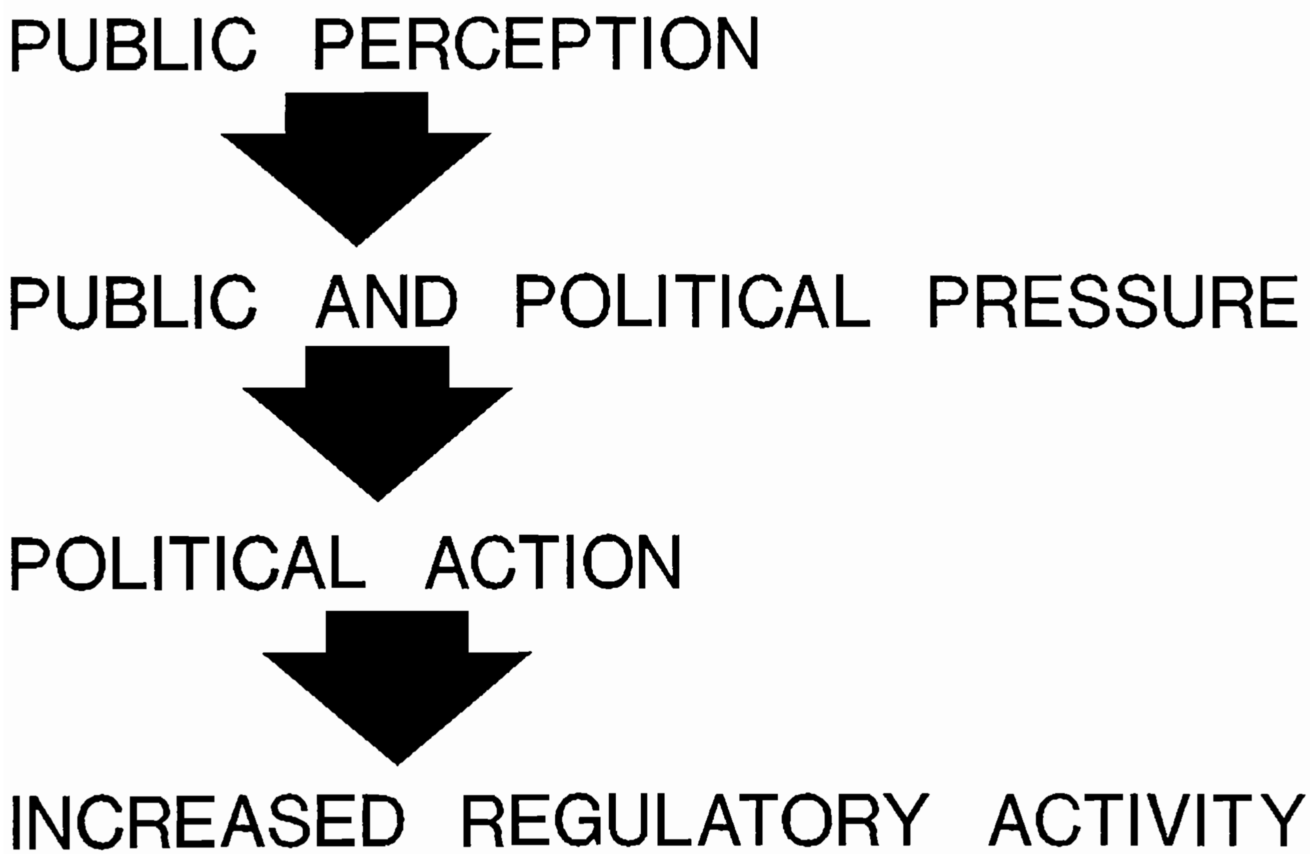


Figure 1

ROADMAP TO REGULATORY ACTION

- THE ONE-WAY PLASTIC CONTAINER
- AERIAL SPRAYING
- GRANULAR APPLICATIONS TO TURF
- SPRAY APPLICATIONS TO TURF
- STRUCTURAL FUMIGATION
- INDOOR BROADCAST TREATMENTS
- BARRIER TERMITICIDE TREATMENTS

Figure 2

ENDANGERED SPECIES OF THE 90'S

- AGENCY MANDATES ACTION AND DEADLINE
- AWARENESS PHASE
- PLANNING PHASE
- ACTION PHASE
- REALITY PHASE
- CRISIS PHASE
- COMPLIANCE PHASE (USUALLY DELAYED)

Figure 3

THE CRISIS CONTINUUM

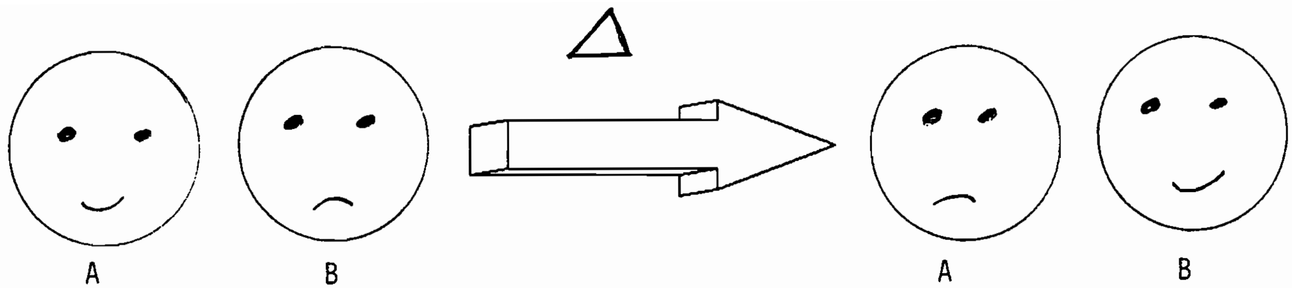
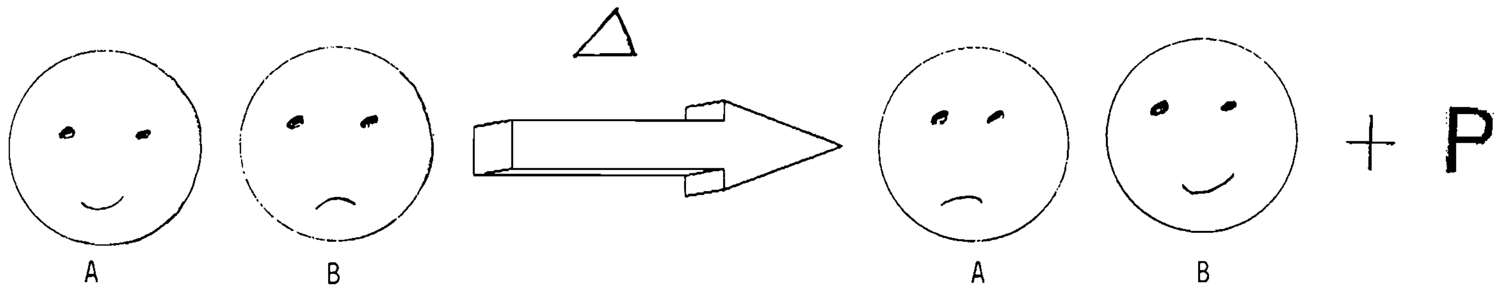


Figure 4

LAW OF CONSERVATION OF BUSINESS PROSPERITY



P = Perception

Figure 5

LAW OF CONSERVATION OF BUSINESS PROSPERITY

1) PERCEPTION = REALITY

2) RISK : : HAZARD

3) PERCEIVED RISK : : HAZARD + OUTRAGE FACTOR

Figure 6

THE SOCIETAL RISK PERCEPTION MODEL

LOW		HIGH
• VOLUNTARY	VS.	INVOLUNTARY
• FAMILIAR	VS.	UNFAMILIAR
• NOT MEMORABLE	VS.	MEMORABLE
• CONTROLLED BY INDIVIDUAL	VS.	CONTROLLED BY SOMEONE ELSE
• FAIR	VS.	UNFAIR
• TRUSTWORTHY	VS.	UNTRUSTWORTHY

Figure 7

VARIABLES OF THE OUTRAGE FACTOR

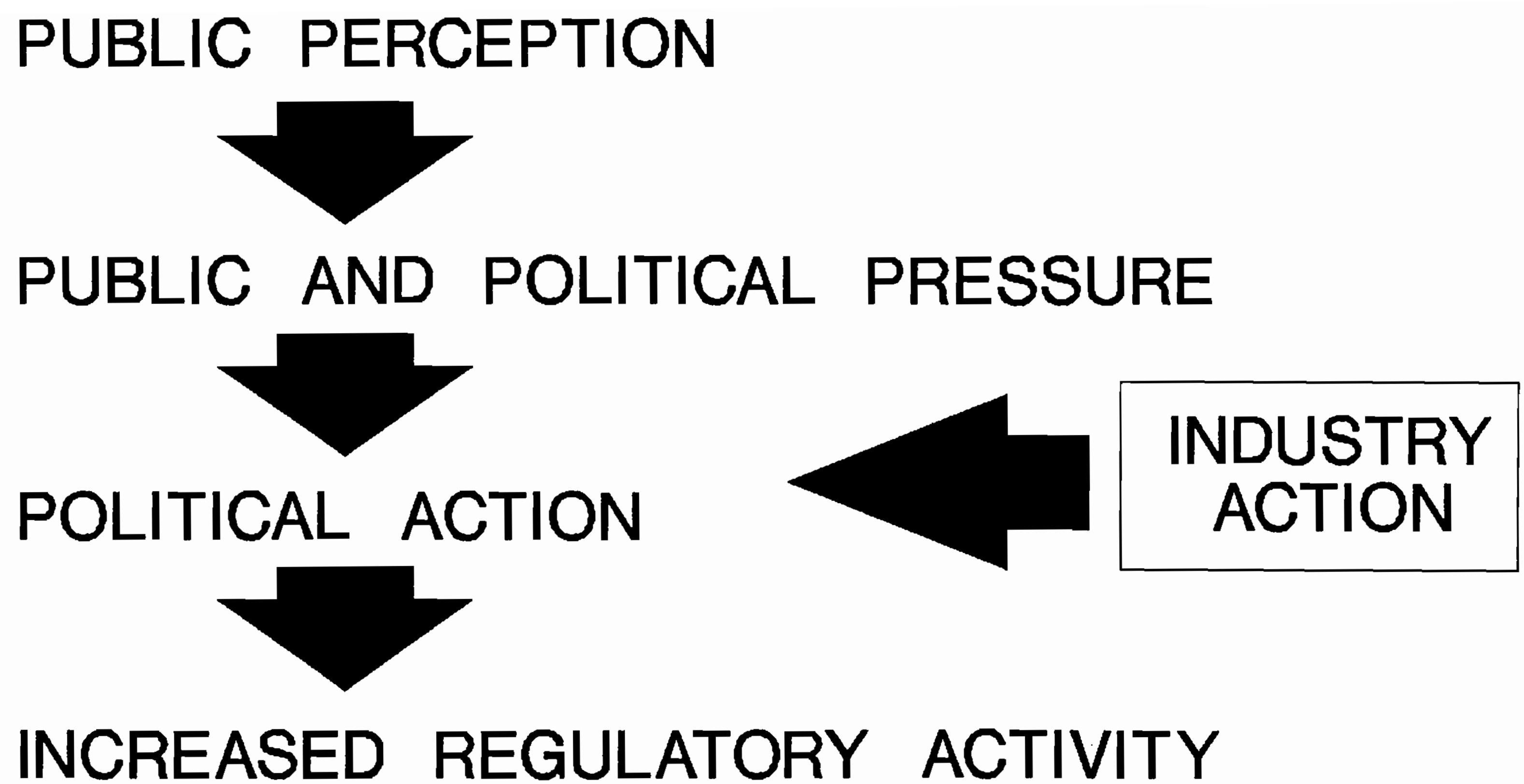


Figure 8

ROADMAP TO REGULATORY ACTION

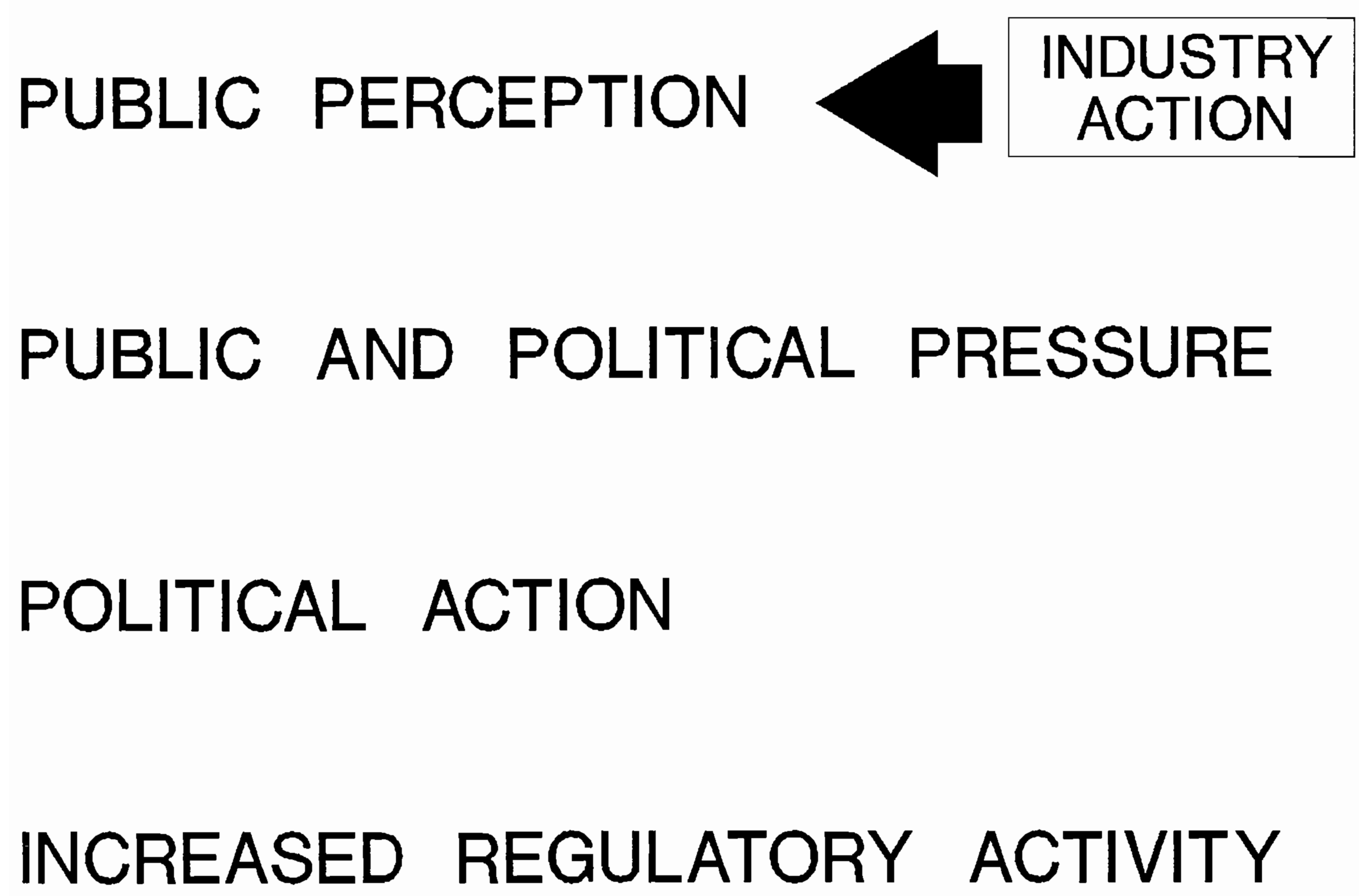


Figure 9

ROADMAP TO REGULATORY ACTION

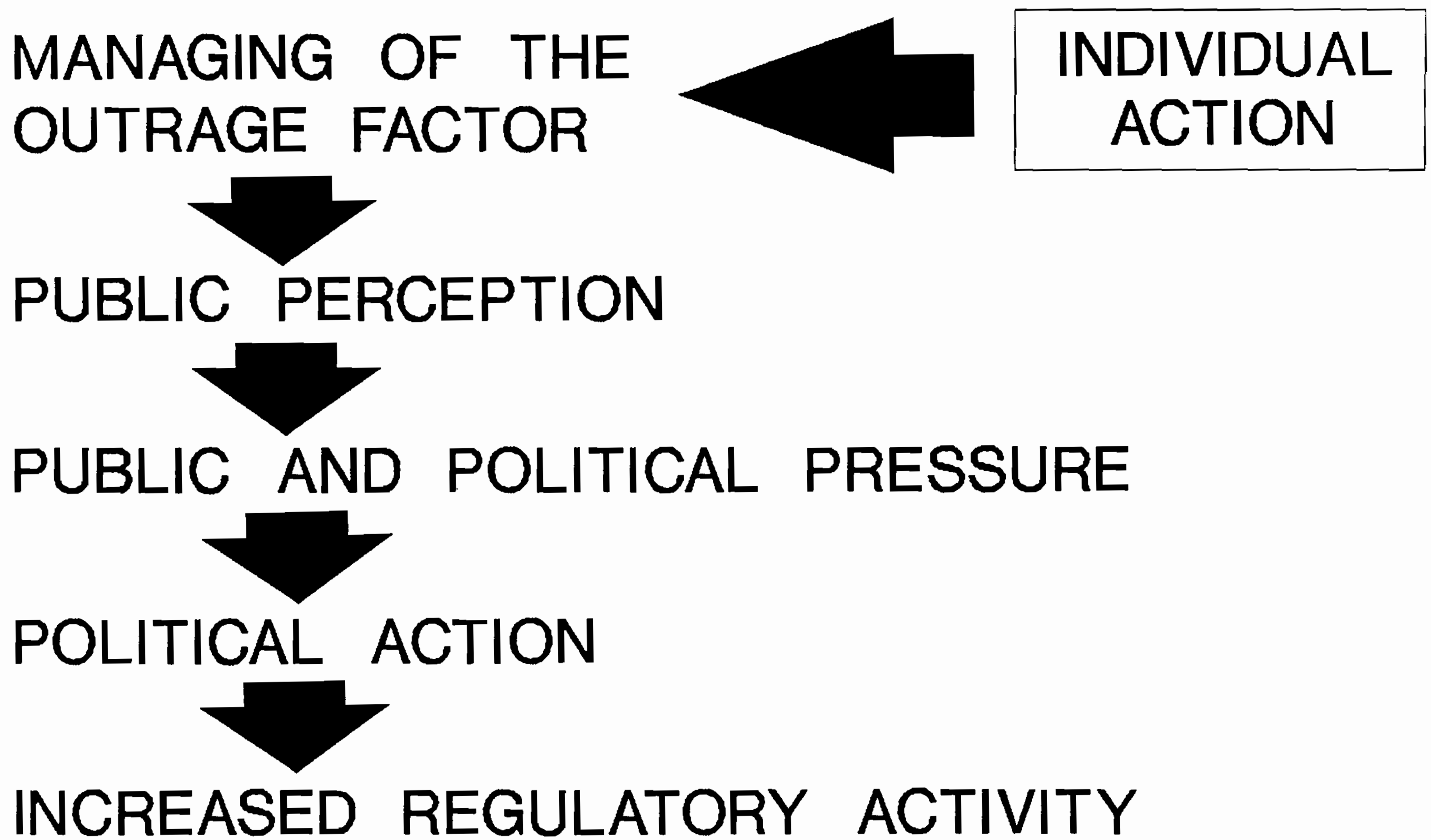


Figure 10

ROADMAP TO REGULATORY ACTION

CARPENTER ANT BEHAVIOR - IMPLICATIONS FOR PEST MANAGEMENT

John H. Klotz

Center for Urban and Industrial Pest Management
Purdue University
West Lafayette, Indiana 47907-1158

ABSTRACT Basic research on carpenter ant orientation has influenced the direction of applied research as well as the recommendations for control. Both bait development and cultural control techniques should be based on knowledge gained from behavioral investigations of home-range orientation.

Home-range orientation, guide-line orientation, delayed action toxicity

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INTRODUCTION

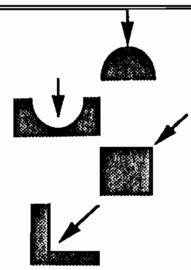
In successful ant control programs, an understanding of the behavioral biology of a pest species is essential. A good example is man's exploitation of trophallaxis in ants to deliver and distribute to a colony a lethal dose of a delayed-action toxicant.

Another important type of behavior which has important implications for carpenter ant control is homerange orientation. Because carpenter ants are central place foragers, carrying resources back to their nest, they must learn the location of resources and hazards within their daily activity range. This kind of learning is known as homerange orientation and can be divided into four components: (1) guide-line orientation, (2) distance orientation, (3) directional orientation, and (4) landmark orientation (Jander, 1977).

BASIC RESEARCH

Guide-line and Distance Orientation

Odor trails are an example of guide-line orientation, and their importance to foraging behaviors in ants has been recognized since the late 18th century (Bonnet, 1779). In contrast to the use of odor trails, the tendency of ants to follow preexisting structural guidelines has received little attention (Jander and Daumer, 1974; Klotz et al., 1985). We classify structural guidelines into four basic types (Fig. 1), and each type may be used differently by ants when they orient along their surfaces (Klotz & Reid, 1992).

Type of Element	X-section[1]	Examples
1. Bilateral - elevated (positive):		plumbing pipes or electrical conduits
2. Bilateral - depressed (negative):		grooves in wood paneling or linoleum tile
3. Unilateral - elevated (positive):		edges along a counter or table top
4. Unilateral - depressed (negative):		edges created where wall meets the ceiling or floor

1 - arrows indicate the edge referenced when defining a guide-line.

Fig. 1. Classification of structural guide-lines found within man-made structures.

There are a number of spatial cues which mediate structural guide-line orientation, including thigmotactic, gravitational, chemotactic and phototactic cues. We have discovered several rules which ants follow in the use of these cues for structural guide-line orientation:
(1) Adherence to these guide-lines is more pronounced on vertical than on horizontal surfaces and more pronounced in darkness than in daylight.
(2) Orientation switches from a crestline on the horizontal to a groove on the vertical.
(3) Light and odor trails serve an important role as extrinsic distance cues in structural guideline orientation.
(4) In crest-line orientation ants oscillate side-to-side along the crest-line, turning up-slope after reaching a particular angle down from the horizontal.

Adaptive Significance: Whenever ants orient within man-made environments they must find their way in a three dimensional maze of structural elements. Since this is not unlike the complexity they confront in nature, natural counterparts to structural guide-line orientation should exist.

We have observed species of ants following naturally existing guidelines: *C. pennsylvanicus* (black carpenter ant) exhibiting crest-line trailing on branches lying on the forest floor, or following ridges and grooves in the bark of tree trunks, and *Crematogaster* spp. (acrobat ants) using vine stems to orient up and down along a tree's trunk. These naturally existing guide-lines provide quick and easy access for traversing territory that otherwise might obstruct an ant's progress, resulting in the ants following the path of least resistance and thus conserving energy. However, fidelity to these guide-lines diminishes as the detour away from the final destination increases. These guide-lines might also confer a measure of safety from predators or inclement weather, relative to crossing open and exposed surfaces. In the case of crest-line orientation, orientation to gravity keeps ants atop the structural element (Klotz, et al., 1985), thereby avoiding the underside where they are prone to falling off (Jander, 1990).

Hints as to the adaptive significance of structural guide-line orientation may be found by looking to other invertebrate, as well as vertebrate, household pests exhibiting this behavior. Many common household cockroaches are thigmotactic (Bell, 1981; Berthold & Wilson, 1967), and thus gain harborage within cracks and crevices and travel along unilateral edges (Fig. 1). An in-depth study of guide-line orientation (Jander & Daumer, 1974) in the genera *Macrotermes* and *Hospitalitermes* demonstrated the importance of crest-line orientation to these blind, open-air foraging termites. We have also noted a tendency in a subterranean termite, *Reticulitermes flavipes*, for building mud shelter-tubes along the edges of woodworkings and utilities in man-made structures. Because they are primarily nocturnal, rodents rely upon tactile orientation by utilizing their vibrissae and guard hairs to contact with vertical surfaces (e.g. walls) along their runways. Further, mice observed in the wild often exhibit a "corner response," in that they gravitate towards corners which enables their guard hairs to have contact with two adjacent walls while they feed or rest (R.M. Corrigan, pers. com.).

A restricted use of vision for orientation behaviors is a common thread in each of these examples of using structural elements in orientation. In our study, one of the ants, *C. pennsylvanicus*, is primarily nocturnal (Klotz, 1984), and relies less on visual than on chemical cues when compared to diurnal ants, like *Formica subericea* (Klotz, 1986). For blind organisms, like termites or some army ants, and nocturnal organisms where vision is restricted (e.g., rats, mice, cockroaches, and many ants) tactile cues would be important stimuli for topographic orientation. In all such organisms infesting man-made structures, structrual guide-line orientation is an integral component of their spatial orientation repertoire.

Directional and Landmark Orientation

The black carpenter ant, a predominantly nocturnal ant, responds to a hierarchy of visual and tactile cues when orienting along odor trails at night. Workers rely upon the illumination from moonlight or artificial light to mediate phototactic orientation. In the absence of moonlight or artificial lights, ants were able to orient visually to terrestrial landmarks. In the absence of all landmarks, except overhanging tree branches, ants can negotiate shortcuts or make directional changes in response to visual landmarks presented within the tree canopy on a moonless night. When experimental manipulations placed the ants in total darkness, they could no longer negotiate shortcuts and would resort to thigmotactic orientation along structural guidelines to reach a food source.

Adaptive Significance: Our studies have shown that a relatively bright source of light, such as the moon or a floodlight, can serve as a primary directional cue for night orientation in C. *pennsylvanicus*. Terrestrial landmarks are also important cues in nocturnal orientation. Our experiments suggest that C. *pennsylvanicus* responds to landmarks within tree canopies as nocturnal orientation cues, as similarly reported in *Paltothyreus tarsatus* (Holldobler, 1980). Kaul & Kopteva (1982) point out that nocturnal orientation to landmarks is more dependent on sufficient contrast of the landmark to the background than it is on levels of illumination. Given this assertion, and Holldobler's (1980) argument for canopy orientation being well suited to restrictive lighting conditions in tropical forests, response to canopy landmarks by C. *pennsylvanicus* under the low light conditions during our studies is understandable. Considering that C. *pennsylvanicus* typically nests within trees, the species' adoption of canopy landmarks as orientation cues may be an adaptation that increases the likelihood of workers returning to the tree, and thus the nest, after foraging sorties. Olfactory cues in the odor trail would be important backups to directional and landmark cues, given the very low light conditions under which nocturnally active ants sometimes forage.

APPLIED RESEARCH

Black carpenter ants are often significant pests in suburban areas adjoining woodlands, and can cause substantial damage to wooden structures. In the northeastern US, their economic significance rivals subterranean termites (Fowler 1983). Present chemical controls depend on broadcast applications of insecticidal barriers that thwart carpenter ant movement into protected structures, supplemented with labor-intensive searches to find nest sites for direct treatment of the colony (Akre & Hansen 1990). These strategies, while effective, place pesticide residues in environments intimately associated with human activities. In their study on the contact toxicity of several insecticides to *Camponotus* spp., Gibson & Scott (1989) concluded that baits, incorporating slow-acting poisons in an attractive food, would be a valuable tool in carpenter ant management.

Effective ant baits possess three essential properties: 1) an effective attractant, typically a food material, with some specificity towards the target species; 2) an inert carrier that is highly palatable and readily gathered by the target species; and, 3) a non-repellent toxicant exhibiting delayed-action over a 10-fold (or greater) range of dilutions (Stringer et al. 1964). These principles, defined in developing baits for red imported fire ants, have had wide application in bait development for other social insects (Edwards 1986, Ethridge & Phillips 1976, Reid & MacDonald 1986, Su & Scheffrahn 1991). No studies have applied these principles to the development of toxic baits for *Camponotus* spp. With the recent development of new, delayed-action insecticides, toxicity studies are needed to facilitate bait development for the carpenter ants.

Abamectin (avermectin B1a) and sulfluramid (N-ethyl perfluorooctane sulfonamide) are known to possess the delayed-action necessary for baiting social insects and both have proven effective against other ant species (Lofgren & Williams 1982, Vander Meer et al. 1985); dechlorane was evaluated to provide a historical contrast with this known effective ant-bait toxin. Objectives in this research were three-fold: 1) to demonstrate delayed-action toxicity following ingestion of the toxins by foraging *C. pennsylvanicus* (primary toxicity tests); 2) to contrast toxicant activities over a wide range of dosages; and, 3) to determine what impact trophallaxis has upon toxicity (secondary toxicity tests). In realizing these goals, this research sought to generate a database to aid in making decisions on toxicant dosage in any subsequent bait development research.

In the primary toxicity tests, each toxicant displayed delayed-action over a 10-fold dilution, indicating a high potential for success as a bait toxicant (Stringer et al. 1964), there was one, potentially important difference. Abamectin was more rapidly acting than either dechlorane or sulfluramid. At 500 ppm, abamectin killed the ants in 1 or 2 d (Fig. 2), much sooner than ants feeding on higher concentrations of the two other toxicants. Moreover, the delayed-action toxicity displayed by abamectin spanned a narrower range of concentrations than either dechlorane or sulfluramid (Fig. 2).

Considering the rapid death of ants that fed upon baits with 500 ppm abamectin, compounded by their survival when fed concentrations below 25 ppm, abamectin might be less suitable as a toxicant than sulfluramid in baits for *C. pennsylvanicus*. If formulated at too high a concentration (e.g., 500 ppm), abamectin baits could be so fast acting that they might only kill (or behaviorally impair) foraging carpenter ant workers. This outcome would likely forestall the introduction of significant quantities of toxic bait into a colony. If formulated at too low a concentration, the abamectin bait might be

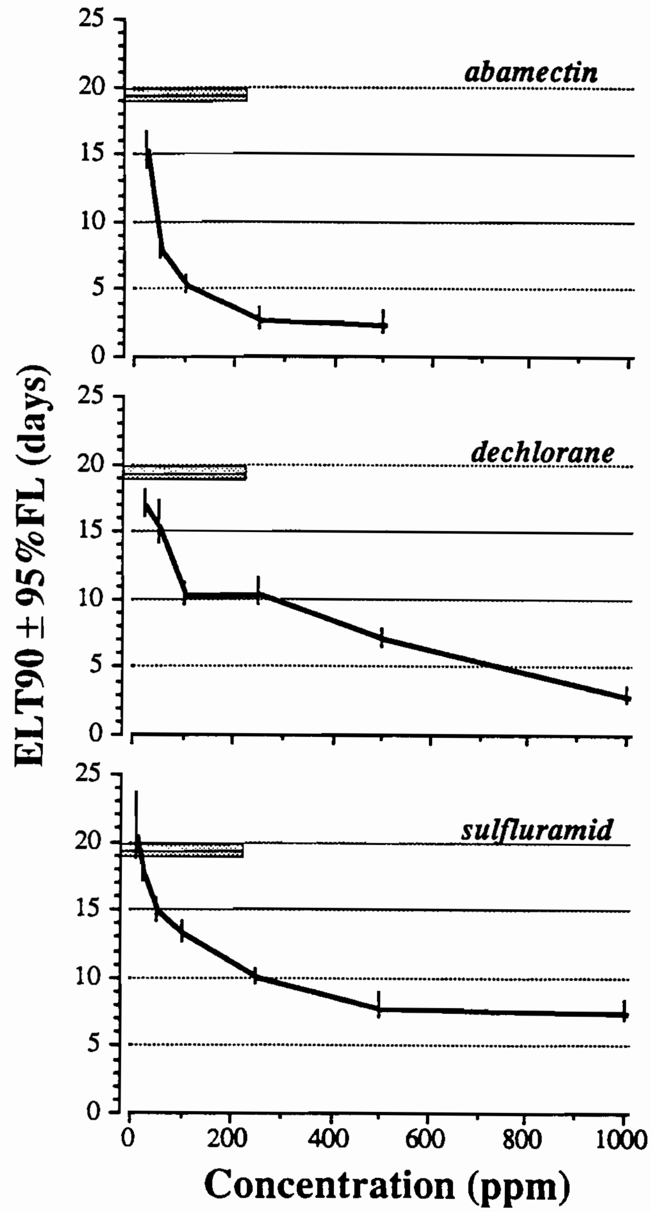


Fig. 2. Time (days) elapsing before 90% mortality (ELT90±95% FL) of free-foraging *C. pennsylvanicus* workers ingesting various concentrations of either abamectin, dechlorane or sulfluramid. Shaded bar extending from Y-axis is the ELT90±95% FL for controls.

too readily "diluted" through trophallaxis to levels that might not even kill the workers. However, this speculation does not consider abamectin's ability to sterilize the queen, as has been shown in the red imported fire ant (Lofgren & Williams 1986). Low doses of abamectin reaching the queen after trophallaxis might compensate for a lack of mortality among workers.

Further, baits containing abamectin are highly effective against the red imported fire ant (Greenblatt et al. 1986). Certainly, this line of speculation should be investigated during field trials of abamectin baits for carpenter ant suppression.

In the secondary toxicity tests, the time delay before death of recipient ants was significantly increased (relative to LT_{50}s in primary toxicity tests) by social dilution through exchanges with the donor ants; the only exceptions were for sulfluramid at 500 and 50 ppm. For the higher concentrations, slopes of the regressions of secondary toxicity data were shallower than in the primary toxicity testing. Shallow slopes indicate a less uniform response or uneven dosing in the recipient ants. These observations point to an unequal distribution of toxic sugar-milk from the donor to the recipient ants. Support for this conclusion is found in two studies on food exchange in *C. pennsylvanicus*. Brunhaber (1973) reported that, on average, over 50% of the crop contents of a donor ant may be passed on to a single recipient ant. Traniello (1977) found that while *C. pennsylvanicus* donor ants transferred over 95% of the volume from a single feeding on P^{32}-labelled honey-water to nestbound cohorts, the liquid distribution among these nestmates varied by more than a 100-fold.

C. pennsylvanicus nest locations are cryptic and difficult to find. Therefore, toxic-baits developed for carpenter ants would have to be placed along active foraging trails or other sites of known foraging activity. In this scenario, efficacy will be more dependent upon the attractant matrix being able to draw the ants to the bait, and stimulating sustained recruitment to facilitate the continued infusion of the toxicant into the colony. An attractant matrix stimulating only weak or mild recruitment might prevent sufficient toxicant from being introduced into the colony before foraging workers are behaviorally impaired and stop gathering the bait. Our concerns for the efficacy of a weakly attractive bait-matrix would be amplified if the toxicant concentration killed the worker ants too quickly. Therefore, when developing attractant matrices for carpenter ants, researchers should also consider the biological and behavioral factors that effect the rate of recruitment to the bait and the pathways of trophallaxis within the colony for the food material.

IMPLICATIONS FOR PEST MANAGEMENT

Carpenter ants have a highly evolved, successful orientation system, enabling them to travel several hundred meters from the nest (taking a highly circuitous route), then locate a resource, and finally take the shortest straight-line path back to the nest. Exploiting our knowledge of their orientation can play a crucial role in their control. Since effective baits are still yet to come for carpenter ants, the only way to eradicate them is to locate and treat their nest. This is a difficult and time consuming procedure, but may be accomplished by feeding foraging ants a little dab of honey or sliced-up insects, and then following them on their homeward journey.

It is essential for control to find and eliminate the parent colony. In order to locate the colony, a thorough inspection is necessary. As in termite inspections, a written record should be kept in the form of an inspection diagram indicating areas of ant activity as well as nest locations. Inspections for carpenter ants should be carefully and thoroughly performed; therefore, they are the most labor-intensive part of the control program.

Ideally, inspections should be performed at night, since most species of carpenter ants are nocturnal. Large numbers of ants emerge after sundown, and an equally dramatic number of ants disappear into the nest at sunrise. This is the best time to locate nests and map out trail routes. Night inspections will become even more critical when baits are available, since their placement should be along known routes of travel for the ants.

It is helpful to keep in mind that ants have a propensity for traveling along the various structural and utility lines found within our structures. For example, ants utilize all types of conduits, plumbing lines, electrical lines, duct channel lines, exterior lines, and other lines to travel from one area to another. The inspector should inspect these lines for the presence of ants, keeping in mind all vertical lines within the facility as well as horizontal lines. Also, it is important to inspect those areas and items where the various lines may terminate, such as junction boxes, electrical switch panels and the like. This approach to inspection and treatment is the *"Lines Perspective"*(Corrigan & Klotz) . We have exploited the ants' natural tendency to use these pre-existing guidelines to channel them to feeding stations where we have tested various toxic baits for carpenter ant control. Knowing that ants use these structural guidelines for entering and traveling throughout structures narrows the focus for inspection and treatment. In treatment this behavior should narrow the target areas. For example, if you suspect a nest is located in a wall, treat behind the electrical switch plates or pipe flanges, where the ants travel along the wires or pipes. Rather than treating large open areas where the ants are unlikely to travel, a minimal amount of pesticide is applied along known runways.

Openings created where pipes or electrical lines enter a house should be caulked. This cannot be emphasized enough since, hypothetically, if you can seal all the gaps and holes into a structure you will prevent any ant problems from ever occurring.

SUMMARY

Basic research on orientation of ants has direct implications to the focus of applied research with bait and perimeter treatment studies, and for new ways or strategies of controlling these ants.

The behavioral approach can serve as a model for continued research on ants that are structural pests, to investigate their basic behavior and orientation, with the goal of directing their movement into more concentrated areas so that they can be baited, or controlled by other traditional pest control techniques. An understanding of a pest's behavior is critical for any successful program of control.

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SAMPLING GERMAN COCKROACH FIELD POPULATIONS: THEORY, RELIABILITY, AND ANALYSIS

Arthur G. Appel and Byron L. Reid

Department of Entomology, 301 Funchess Hall, Auburn University, AL 36849-5413; Center for Urban and Industrial Pest Management, Department of Entomology, Purdue University, West Lafayette, IN 47907

ABSTRACT Field evaluation of insecticides for German cockroach, Blattella germanica (L.), control requires the use of various population sampling techniques. Population sampling can best be accomplished when the underlying spatial distribution pattern is understood. Based on both sticky trap and visual counting methods, German cockroaches have a contagious distribution. This pattern is visible within apartments, among apartments within complexes, and among complexes. Through the use of a mathematical description of the distribution pattern, the parameters estimated with Taylor's power law allow the calculation of the number of apartments necessary to estimate a given population size with a known level of precision.

Keywords- German cockroach, spatial distribution, sampling, Power law, experimental design, analysis

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Most urban entomologists conduct field trials on insecticide efficacy against German cockroaches, Blattella germanica (L.) (Dictyoptera: Blattellidae). Typically, these field trials begin with the selection of scores, if not hundreds, of apartments for trapping. The apartments are usually trapped with 2 or 3 sticky or jar traps for between 1 and 7 days. The traps are then counted and the total number of cockroaches trapped in each apartment is recorded. The apartments are then ranked from highest to lowest catch, and allocated to the various treatment groups much like dealing cards in a poker game. Care is usually taken to allocate pretreatment catch in such as way to have equivalent mean numbers in each of the treatment groups. Treatments are then applied and trapping typically occurs at 1, 2, 4, 8, and 12 wk after treatment. Percentage reduction is usually analyzed and "significant differences" of as little as 2 or 3% have been reported in the literature. We believe that in most cases, these small differences are unrealistic and inconsistent. The goal of this paper is to critically examine the basic assumptions of German cockroach population sampling and propose more theoretically and realistically based methods for sampling and data analysis.

SAMPLING METHODS

The first sampling of German cockroach populations, used in Germany in the early 1900's, consisted of the use of smoked glass plates to detect the movements of cockroaches. A variant of this method, the sooted paper, was used by the Japanese in the 1960's. Both programs used movement tracks to crudely quantify abundance; if there were fewer tracks, then there were fewer cockroaches.

Sampling methods can be divided into two general categories, destructive or removal methods and nondestructive methods. Destructive methods include sticky traps and the UCR jar trap with dry clay. Nondestructive or live traps include a variety of greased jars and the "electric can". Another commonly used nondestructive sampling method is visual counting. With the aid of a flashlight and mirror, the number of cockroaches is counted in specific areas (zone counting) or throughout a kitchen or apartment. Application of a flushing agent such as pyrethrum prior to counting (flush and count) has also been utilized. In general the visual counting methods tally all individuals without regard to stage or sex. Visual counts are also very time consuming, as a typical apartment may take up to 20 minutes to evaluate. Visual methods also ignore the basic spatial distribution of cockroaches within and only give the total number of cockroaches per apartment. Because of these and other limitations of visual counting, the balance of this paper will primarily deal with the results from trapping studies.

What is sampling? According to Morris (1954), "Sampling has no intrinsic merit, but is only a tool...". Sampling gives us a measure of a larger population. Sampling does not give us the "real" population size. We therefore must remember to think about the data from our studies as reductions in trap-catch and not absolute reductions in population size. Because sampling is a measure, the results are not exact, i.e., there is variation about these estimates.

Sampling can be used for a number of different purposes, each with different requirements for variation. Detection or presence-absence sampling answers the question: are there cockroaches here? Variation is not an issue, a single cockroach might be enough to initiate a response. Sampling is most commonly used to quantify the relative size of an infestation, either among apartments or time intervals. This type of sampling is employed to determine whether there are more cockroaches present in one apartment than another or if a given insecticidal treatment reduce cockroach populations. Qualitative information such as the pest species present or the age-class structure of a population may also be obtained. Age-class structures are particularly important when insect growth regulators (IGR's) are evaluated. Combined, this quantitative and qualitative information from traps can be used to examine the population ecology of cockroaches with a view towards understanding the behavior and evolution of cockroach populations.

This paper will focus on German cockroach sampling as it is conducted, or should be conducted, for insecticide efficacy testing. A more precise understanding of sampling methods and data analysis will lead to more accurate tests for product discovery, development, comparisons, and ultimately product recommendations for the professional pest control industry and for the consumer. Better evaluation methods will also save time and money in the development of new and better products.

No matter what methods researchers are using when evaluating insecticide performance, we need to know the advantages and limitations. In this way, more valid comparisons can be made among the results of different experiments and researchers. We are not implying that all field trails should be conducted with one protocol, this is not a call for uniformity or standardization in methodologies. We are calling for a greater awareness by researchers of the advantages and limitations of their methods and we are also calling for better science in our field studies. Our goal is to present some basic biological and ecological concepts and then to apply these concepts to understanding the German cockroach and evaluating the performance of insecticides.

DISPERSION OF GERMAN COCKROACHES

Of all the fundamental aspects of the biology of German cockroaches that impact our sampling programs, none is more important than the species' distribution in space. While other biological factors, such as survival or reproduction, are highly dependent on local environmental conditions and vary considerably from one locale to another, spatial distributions display remarkable consistency among very different environments. Analysis of the spatial distribution patterns for a species will yield characteristic parameters which are a direct consequence of individual behaviors being manifested at the level of the population (Taylor 1984). Accordingly, our discussion of German cockroach spatial dispersion will begin with a brief overview of salient features in the behavioral ecology of the German cockroach. We then consider how environmental conditions within a habitat (e.g., an apartment) modulate the expression of these behaviors to organize spatial distribution patterns.

Behaviors and the Environment

The German cockroach is a gregarious animal. In fact, a reasonable argument could be made for German cockroaches being a communal organism, where members of the same generation use the same composite nest without cooperating in brood care (Wilson 1971). The dense groupings of individuals within harborages would produce large deposits of aggregation pheromone, such that these areas can be considered a "chemical nest" of sorts. Popular understanding of German cockroach biology is such that these harborage sites are often referred to as 'nests' by the public, and many insecticidal bait products refer to the cockroach 'colony' in their labeling. There is sufficient evidence to conclude that group living confers significant advantages to the individuals in an aggregation. Development times are accelerated by group living and survival rates, particularly among early instars, are likely increased. The presence of so many individuals in the small spaces typical of harborage sites suggests the possibility that German cockroaches, by aggregating with conspecifics, may be capable of limited modifications in environmental conditions, especially temperature and humidity. The net effect of the photonegative behavior of German cockroaches, along with their positive thigmotaxis, is to regulate the organism's exposure to inclement environments. All these behavioral features combine to restrict the activity of German cockroaches in space and promote the assemblage of individuals in a population. These biological realities define the spatial distribution characteristics of this species.

Indoor environments typically inhabited by German cockroaches are composed of a wide variety of microhabitats, each providing resources (harborage, temperature, water and food) in spatially variable quantities and qualities. Not surprisingly, German cockroach populations are unevenly distributed in these highly heterogeneous environments (Schal & Hamilton 1990). The spatial distribution of German cockroach populations in apartments are a by-product of the environmental heterogeneity within the apartment. To substantiate this point, we provide the following data from our trials of insecticide efficacy in multifamily apartments.

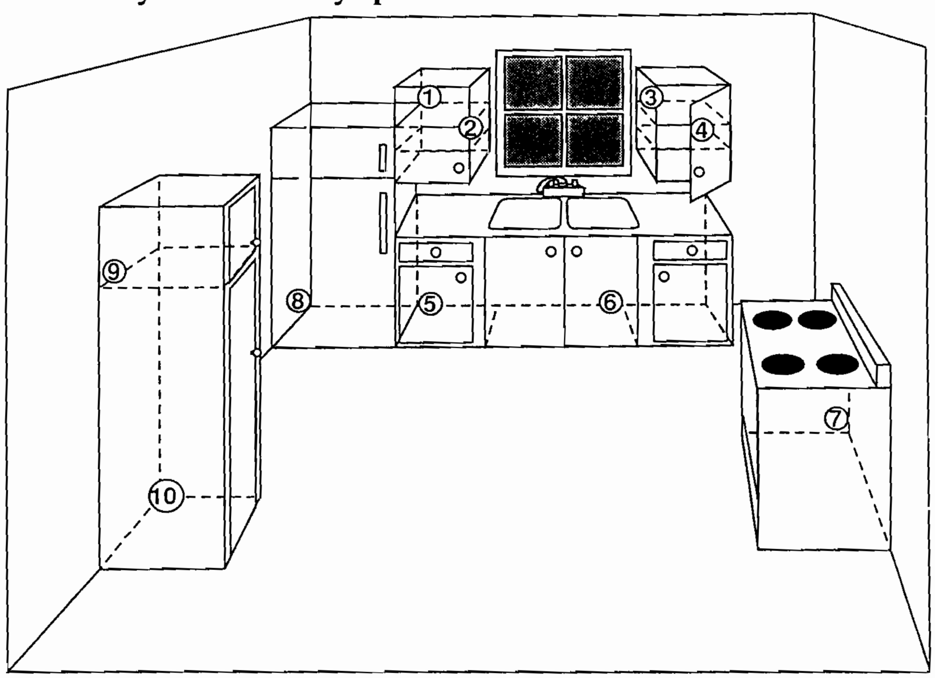

Fig. 1. Sticky trap locations used to sample German cockroaches in kitchens in Opelika, Alabama.

In 1990, fifteen apartments in a housing complex in Opelika, Alabama were examined. Residents in these apartments had chosen not to be treated with insecticides. In each apartment, ten traps (Mr. Sticky, LTP, Bronx, NY) were situated in various sites in the kitchen: cabinets under and above the sink, the stove and refrigerator, and a pantry cupboard (Fig. 1). After 7 d the traps were retrieved and the catch was enumerated by life stage (e.g., small and large instars, and adult males and females). In 1986, sixty-four apartments from complexes in Michigan City, Muncie and South Bend, Indiana were examined. These were the compliment of apartments in the insecticide efficacy studies reported by Reid et al. (1990). In each apartment, three to six traps (Raid™ Roach Traps, S. C. Johnson Wax, Racine, Wis.) were situated in various sites in the kitchen and bathroom(s) and, after a 24 h sample period, the traps were retrieved and the catch was enumerated as described earlier.

bathroom(s) and, after a 24 h sample period, the traps were retrieved and the catch was enumerated as described earlier.

The data from Alabama (Fig. 2) display a highly uneven distribution of trap catch among the ten sites. Trap catch was highest at the refrigerator and stove, with the next largest catch at one of the traps in the pantry. In this example, higher trap catch (and, presumably, higher population density) was associated with areas providing key resources, such as water at the refrigerator and food at the stove and pantry.

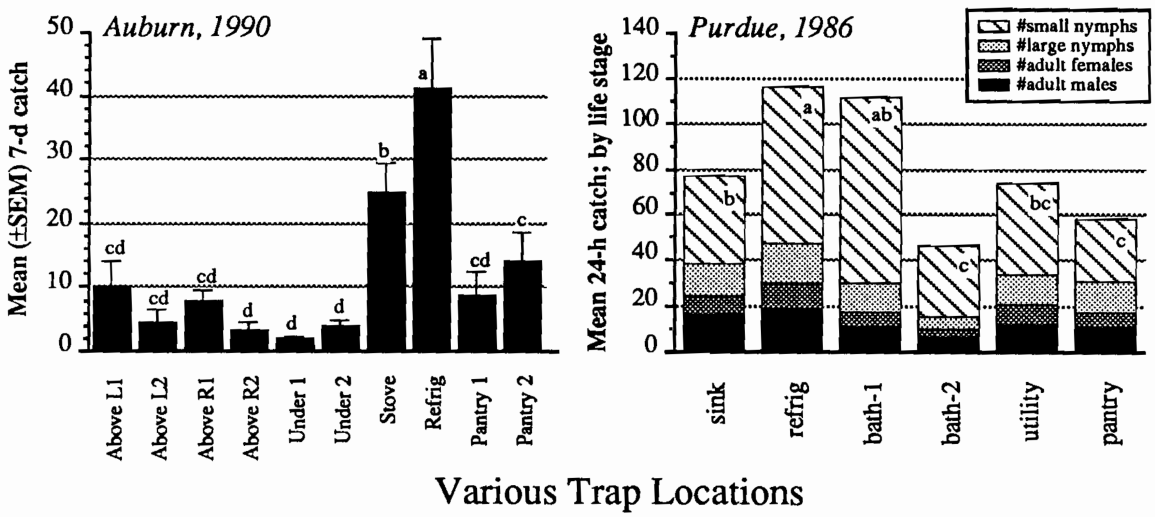

Fig. 2. Focality of German cockroach infestations within apartments, as described by variation in trap catch among different trap locations. Significant differences in trap catch between trap locations are indicated by different letters (Waller-Duncan k-ratio t-test; $P < 0.05$).

The data from Indiana (Fig. 2) display the same uneven distribution of trap catch as a function of trap location, with the highest catch occurring at the refrigerator and the main bathroom. In this figure, trap catch is separated by life stage to illustrate that much of the variation in trap catch between sites is a function of the number of small (1-3 instar) nymphs captured. This observation suggests that trap sites with higher catch rates may be associated with microhabitats where reproduction and nymphal survival are favored.

SPATIAL DISTRIBUTIONS ARE CHARACTERISTIC

We can formalize the expression of the distribution of German cockroach populations in space with the variance to mean ratio ($\sigma^2 / \bar{x}$), which is the simplest of the dispersion indices developed for ecological research. For details of this and other procedures we refer the reader to the discussions in Seber (1982), Southwood (1978) and

Taylor (1984). The $\sigma^2 / \bar{x}$ will indicate whether the spatial distribution in our trap data is uniform ($\sigma^2 / \bar{x} < 1$), random ($\sigma^2 / \bar{x} = 1$), or clumped ($\sigma^2 / \bar{x} > 1$). Statistical significance of the $\sigma^2 / \bar{x}$ values are determined with the index of dispersion, which is approximately distributed as c2 with n-1 degrees of freedom (Southwood 1978). In a random distribution the probability of the organism occupying any point in space is equal, and the presence of one individual does not influence the distribution of another. We know that neither of these conditions are met for German cockroaches and expect the $\sigma^2 / \bar{x}$ of our sample data will indicate a clumped, or contagious, distribution. Therefore, our intention is not simply to determine the spatial distributions, but rather it is to compare dispersion patterns of various data sets to establish the fact that dispersion patterns are characteristic to German cockroach populations.

Dispersion Within Apartments

Runstrom & Bennett (1990) analyzed the spatial distribution of German cockroach populations within 12 apartments. Data were gathered by nondestructive, baited jar-traps placed overnight at 40 sites throughout the two-story apartments. They reported finding a $\sigma^2 / \bar{x}$ of 25.9 for all apartments, indicating a significant ($P < 0.01$), contagious distribution. For comparative purposes, we applied dispersal analysis to the average trap catch from the various trap locations presented in Fig. 2. From the Auburn data, these procedures yield a $\sigma^2 / \bar{x}$ of 12.05, while analysis of the Purdue data resulted in a $\sigma^2 / \bar{x}$ of 9.64; both of these $\sigma^2 / \bar{x}$ indicate a significant ($P < 0.005$), contagious distribution.

The $\sigma^2 / \bar{x}$ from our data do differ from that of Runstrom & Bennett (1990). With their greater number of traps (40 vs. 10 or 6), they sampled in some areas (living rooms and bedrooms) with predictably low trap catches, areas that our traps in kitchens and bathrooms did not consider. The result would be a greater frequency of low trap catches that would have a tendency to increase $\sigma^2 / \bar{x}$. Nevertheless, the $\sigma^2 / \bar{x}$ values are quite similar among these three data sets and demonstrate the similarity in dispersion patterns. This observation is even more significant considering the differences in sampling methods and geographic locations represented by these data.

Dispersion Within Apartment Buildings

To examine dispersion patterns between apartments within buildings, we will consider data found in Akers & Robinson (1981) from a trapping study on the density of German cockroach populations within apartment buildings. The data were obtained with destructive, baited jar-traps located at two sites in the kitchen and one in the bathroom of each apartment. Each building contained six apartments, and we analyzed cumulative trap catch (8 wk) among the apartments in each of the three buildings included in the study. The $\sigma^2 / \bar{x}$ generated from these data were 435.50, 286.43 and 667.68, and indicate significant ($P < 0.001$), contagious dispersion patterns for populations among apartments in a given building. These $\sigma^2 / \bar{x}$ are considerably higher than those calculated from samples within individual apartments, reflecting the greater variability of trap catch between apartments.

As was seen within apartments, where trap sites represented areas that provide varying resource abundance and thus support variably sized aggregations, individual apartments in a building provide even more variable environments. In alluding to this large heterogeneity of habitat, Akers & Robinson (1981) coined the phrase "focus apartment" to denote apartments that provide more favorable habitats for the development of German cockroach populations. While these data are instructive, we need to consider the spatial dispersion of populations among apartments on a much larger scale. In our insecticide efficacy research we typically assign treatments to groups of apartments "randomly selected" (sic) from the scores, if not hundreds, of apartments in the housing complex. It is important to consider the spatial distribution of infestation densities among these apartments, for this is the source for much of the variation in our data sets on insecticide performance. Therefore, the next level of interest is of cockroach population density among apartments within large apartment complexes.

Dispersion Within and Between Apartment Complexes

For this discussion we present results of a sampling program conducted in Gary, Ind. in May, 1988 Three apartment complexes were used for this study: Delaney East, with 228 apartments; Dorie Miller Homes, with 268 apartments; and, Ivanhoe Gardens, with 317 apartments. During a two week period we placed a sticky trap (Raid™ Roach Traps) in the cabinet under the kitchen sink, behind the refrigerator, and in the bathroom of as many apartments in each complex as possible. The traps were retrieved after 24-h and trap catch was enumerated. We were able to recover traps from approximately 65% of the more than 800 apartments in these complexes. For analysis, we used only the total trap catch in each apartment. The frequency distributions of trap catch in each complex, and an average frequency distribution for all complexes, are presented in Fig. 3.

When examining these data, there is a great similarity in the frequency distribution of trap catch in individual apartments. This equivalence is more evident when the data are expressed as the percentage of apartments (to balance for variable apartment numbers). The $\sigma^2 / \bar{x}$ for each of the three complexes are nearly identical, and all indicate significant ($P < 0.001$), contagious distributions. Further, these $\sigma^2 / \bar{x}$ are within the range of those determined for apartments within individual buildings from the data in Akers & Robinson (1981). For comparative purposes, we have applied dispersal analysis to pretreatment density data from our 1991 field trails. In the data from Auburn we analyzed the total catch from 10 Mr. Sticky traps placed throughout the kitchens of 99 apartments for 7 d. The data from Purdue are total visual counts recorded from the kitchen and bathroom in 180 apartments. The results of these analyses are presented in Table 1, along with the data from the 1988 Purdue trapping study.

Table 1. Results from dispersion analysis of various data sets.

Data Set (PI &YR)	Complex	Sample Method	No. of Apts.	$\sigma^2 / \bar{x}$	χ^2-value	*P*-value
Appel-1991	Opelika, Ala.	7-d trap	99	216.55	2.1×10^4	<0.001
Bohnert-1991	Gary, Ind.	Visual Cnt.	180	283.64	5.1×10^4	<0.001
Reid-1988	Delaney East	24-h trap	156	220.57	3.4×10^4	<0.001
	Dorie Miller	24-h trap	187	210.01	3.9×10^4	<0.001
	Ivanhoe Grdn.	24-h trap	195	262.28	5.2×10^4	<0.001

The most striking observation from comparing these data are that the dispersion patterns, as indicated by the $\sigma^2 / \bar{x}$ values, are so consistent given the differences in sampling methods, time and geographic location. We observed a similar equivalence of $\sigma^2 / \bar{x}$ values in the analysis of trap catch data within individual apartments. The important summation from these data is that the gregarious nature of German cockroaches is manifested in these contagious spatial distributions, which are evident whether the scale of observation is within individual apartments, among apartments within buildings or entire complexes, or among apartment complexes.

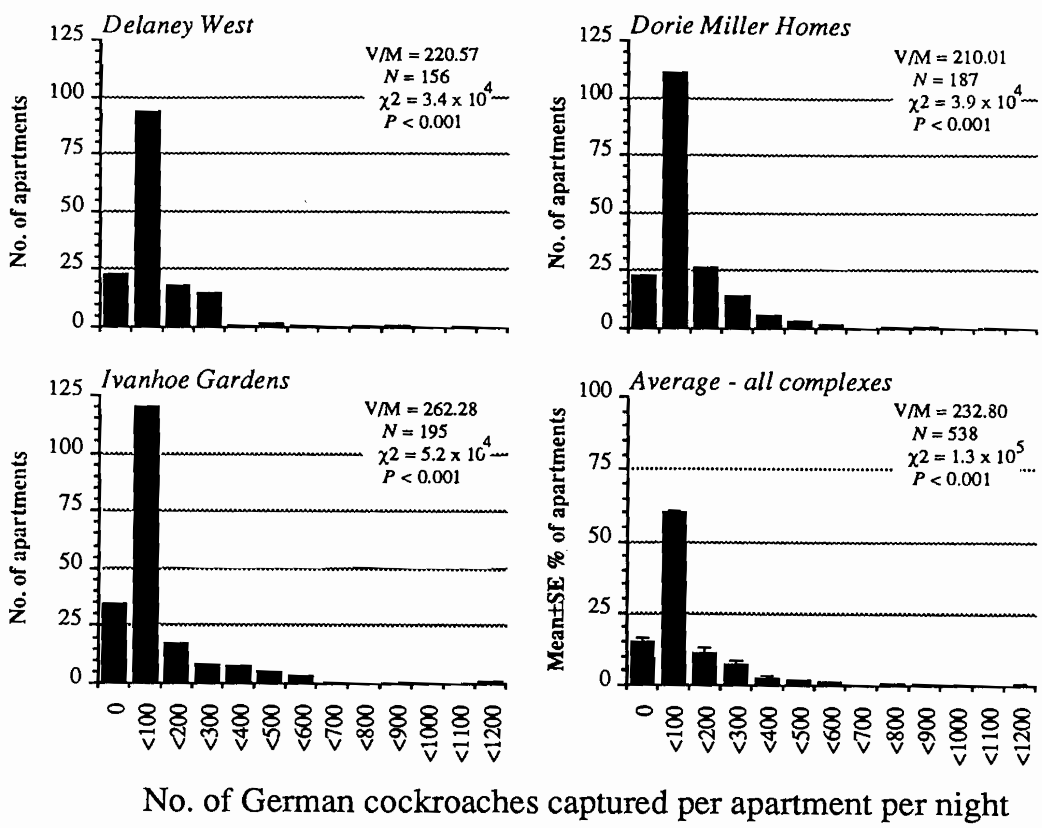

Fig. 3. Frequency distribution of 24-h trap catch (Σ of 3 traps/apartment) in apartments from three complexes in Gary, Ind. Trapping study conducted in May, 1988.
The variance to mean ratio (V/M) is calculated, and $\chi2$ statistics indicate that the populations are contagiously distributed among apartments in all complexes.

Summary

Taylor (1987) observed that one of the major mysteries in ecology today is that the relationship between the variance and the mean, for any species, should be so consistent from year to year, and from place to place. While the ecological significance of these observations are important in the study of German cockroach population ecology, these findings have a profound impact on population sampling. If we are to realize better science in our sampling programs supporting the evaluation of insecticide efficacy, it is important that we recognize the significance of these characteristic spatial dispersion patterns. This will be one theme in the ensuing discussion.

CONCEPTS IN EXPERIMENTAL DESIGN AND DATA ANALYSIS

Dependent Variables

We have now established that German cockroach populations, and any manner of sample data from these populations, are contagiously distributed. This has two important implications in the analysis of efficacy data based on samples from contagiously distributed populations. First, sample data very rarely are normally distributed. Secondly, the data have very high variation, with coefficients of variation as high as 100% being common. These features in our sample data greatly complicate statistical analysis through parametric methods. The most common attempt to solve these problems is to convert the number of cockroaches sampled after a treatment to a percentage reduction from the numbers sampled before treatment. This is done with hopes of equalizing the data, which come from highly variable numbers of cockroaches sampled, by expressing cockroach numbers on a relative basis. This "percent control" is then subjected to statistical analysis.

However, it has been our consistent observation that percent control data are often just as contagiously distributed as the original, untransformed data. In highly aggregated populations, as in German cockroaches, the non-normal distribution of the sample data is too profound to be corrected by this or other transformations (Taylor 1987). The use of distribution-free, nonparametric statistics (e.g., converting counts to ranks before ANOVA) does not solve the problems of analyzing samples from highly contagious populations, because the relationship between mean, mode, and median for a given distribution is always the same (Taylor 1987). Accordingly, it makes little sense to transform the data and we advocate evaluating comparative efficacy by analyzing the actual sample data. However, this does require measures be taken to minimize the variance in the data; these measures are discussed in a subsequent section.

Alternative Dependent Variables

In the annals of insecticide efficacy testing on German cockroaches, there has been one dominant expression for product performance: numerical abundance. On first thought this focus on the number of insects makes perfect sense - cockroaches are an abhorrent pest and the goal for any control strategy is to reduce the size of the pest population. However, our over reliance on numerical abundance as the sole determinant of efficacy has resulted in a very poor understanding of the more subtle effects various control strategies have on the dynamics of treated populations. Considering how relatively simple it is to gather the data from sticky traps on the numbers in different life stages (adult males, gravid and nongravid females, plus various groupings of nymphs), we would be remiss where we to continue to emphasize total trap catch as the only variable of interest when determining efficacy.

While a large variety of data can be generated by fully recording the life stages in trap catch (adult sex ratios, frequency of gravid females, etc.), we emphasize the ratios of nymphs to adults (relative nymphal abundance) as the one alternative variable deserving consideration in every insecticide efficacy trial. Analysis of relative nymphal abundance first came to prominence with efficacy studies on IGRs (e.g., Reid et al. 1990), where the chemicals possess inherent life stage specific activities. However, analysis of nymphal abundance should not be limited to studies on IGRs. Neurotoxic insecticides are known to have differential toxicity among life stages; e.g., adult males are more susceptible than adult females (e.g., Abd-Elghafar et al. 1990). Differences in foraging behavior among German cockroach life stages would lead to variable probabilities of encountering the toxic deposits left by a residual application. Differential foraging behavior would also cause a measure of life stage specific activity with toxic baits, as exposure probabilities would be higher for those life stages more actively feeding. Gravid females, which rarely leave harborage to forage, would be far less likely to be effected by toxic baits than other life stages.

Recognition of stage specific activity in data analyzed from efficacy trails could lead to greater knowledge on the activities of different chemistries and/or formulations. Furthermore, analysis of these nymphal abundance could make it easier to explain why certain treatments work better, or worse, than others by examining differences in activity that are not evident in data for the total sample size. However, it must be remembered that the sampled nymph to adult ratio will be heavily influenced by the inherent sample bias of sticky traps, which tend to over sample adults while under sampling nymphs, especially small nymphs. Thus, just as trap catch does not denote population size, sampled nymph to adult ratios do not measure the actual abundance of nymphs and must be considered as a relative estimator.

Sample Size and Minimizing Variance

Prior to designing an experiment it is critical to clearly understand the goals of the research project, the biology of the pest, the assumptions and limitations of the proposed statistical methods, and have an idea about what you consider biological versus statistical significance.

As we have indicated, descriptions of the spatial distribution of a population are based on the mean and variance. A simple variance to mean ratio ($\sigma^2 / \bar{x}$) describes the basic population dispersion, whereas other estimates including Taylor's power law, Lloyd's mean crowding index, and Iwao's regression and ρ-index provide more detailed information. Taylor's power law describes the relationship between the sample mean and variance. The estimated parameters from Taylor's power law can be used to indicate population distribution patterns, suggest data transformations, and estimate sample sizes with a predetermined level of precision (Southwood 1978).

To critically investigate the spatial distribution patterns of German cockroaches in infested kitchens and the resulting necessary statistical analysis, 15 infested apartments located in Opelika, Alabama were selected for study in 1990. The residents of these apartments did not want any insecticides applied to their residence, but allowed us to trap. Ten sticky traps (Mr. Sticky, LTP, Bronx, NY.) were used to monitor cockroach populations in the kitchens in each apartment. Traps were positioned behind the stove and refrigerator, in the upper and lower cabinets, and in the pantry (Fig. 1). Traps remained in place for 7 d and were then retrieved and counted. The number of adult males and gravid and nongravid females, and small, medium, and large nymphs were recorded. Apartments were trapped monthly for 6 months to maximize the variations in population size.

A split-plot-in-time analysis of variance (ANOVA) and the Waller Duncan k-ratio t-test (SAS Institute, 1988) was used to compare mean trap catch and mean $\sigma^2 / \bar{x}$ among trap positions. The trap positioned behind the refrigerator (No. 8) caught significantly more cockroaches than any other position and was followed by the trap behind the stove (No. 7) (Fig. 2). These two traps and the trap in the lower shelf of the pantry had the greatest variance to mean ratios. These same trends were evident whether the whole population was examined or individual life stages. The $\log_{10}$ (average variance +1) of the number of cockroaches trapped in the 15 replicate apartments was regressed on the $\log_{10}$ (mean + 1) using the 6 trapping periods as replicates. The slope and intercept parameters from this regression were used in Reusink's (Reusink 1980) sample size equation:

$$n = \frac{a\bar{x}^{b-2}}{c^2}$$

where a and b are the regression parameters from Taylor's power law and c is a fraction of the mean $\bar{x}$.

Using the Taylor's regression parameters determined with the traps having the lowest variance, the number of apartments are estimated from Reusink's equation. To estimate a mean of 50 cockroaches with a 5% accuracy and using 10 traps per kitchen, a total of 345 apartments would be needed for each treatment. If an accuracy of 30% of the mean is sufficient, then only 10 apartments are needed. If the traps with the greatest variance to mean ratio (Nos. 7, 8, and 10) are removed from this analysis, then only 180 apartments are needed for 5% accuracy and 5 apartments for 30% accuracy (Table 2). Clearly, much of the variance in trap catch within apartments lies in only three traps. By removing traps with the greatest variance, fewer apartments are necessary for the same precision. Traps locations not used for this analysis should be grouped and analyzed separately. The goal of this procedure is to knowingly partition variance in a reasonable way. Results from high and low variance traps should also be compared.

TABLE 2-- Results of Taylor's power law analysis and Reusink's sample size equation.

Traps	Slope	Intercept	Mean	% of Mean (accuracy)	No. of Apartments
1-10	1.9571	1.0452	50	0.05	345
1-10	1.9571	1.0452	50	0.20	22
1-10	1.9571	1.0452	50	0.30	10
1-6 and 9	1.7843	1.0853	50	0.05	180
1-6 and 9	1.7843	1.0853	50	0.20	11
1-6 and 9	1.7843	1.0853	50	0.30	5
1-6 and 9	1.7843	1.0853	50	0.40	3

ANALYTICAL DESIGNS

Comparisons within a time period

Frequently, comparisons among treatments are made at each of several posttreatment periods during a field experiment. An ANOVA and a mean separation test is conducted at each time period and differences indicate which treatment, if any, is performing better at the given period. Even though this design is able to differentiate treatments, it is essentially a snap shot of performance. This design can not determine consistency of treatments over time. For valid comparisons, a control treatment or reliable (i.e., consistent) standard is necessary. For this analysis and others using the ANOVA and multiple range tests, there are two basic assumptions: 1) additivity of treatment and environmental effects, and 2) random, independent, and normally distributed experimental error. Multiple range tests have their own limitations, especially in the selection of tests that minimize experiment wise versus comparisonwise error rates. Commonly used tests such as Duncan's and Student-Newman-Keuls are no longer recommended by the Entomological Society of America because of their lack of control of experiment wise error rates. Ryan's Q test [in SAS, REGWQ (SAS Institute 1988)] is recommended to control experiment wise error rates, however it is a very conservative test. An example of a simple completely randomized design analysis for comparisons within a time period in SAS is presented in Table 3.

Comparisons among time periods

Comparisons of treatments among time periods have the advantage of allowing the researcher to determine the consistency of the treatment over the entire experimental period. Several different types of analysis are available and it is possible to detect much smaller differences among treatments than with comparisons within time periods. In addition, more information, such as population growth rate, can be obtained with this approach. Comparisons of treatments are somewhat more difficult and we lack good mathematical model with which to fit our data.

A bridge between comparisons with in and between time periods is the split-plot-in-time ANOVA. This approach has the same assumptions as any ANOVA, but allows variation due to apartment and date and their interaction to be partitioned and removed from the error sums of squares. An example of the SAS (SAS Institute 1988) program lines for this analysis is in Table 3.

Regression is the most commonly used analysis for examining variables over a range of time periods. Simple linear regression of the mean number of cockroaches in a group of apartments is often insufficient because of the curvilinear change in means over time. A simple $\log_{10}$(mean + 1) transformation will often linearize the data if the populations do not increase dramatically towards the end of an experiment. If the means do increase at the end of an experiment, then a quadratic regression may be appropriate. A quadratic regression will describe not only the rate of population decline, but the rate of increase as well. Other regression models that combine population growth rates, insecticide degradation rates, etc. have not been sufficiently developed at this time.

TABLE 3-- SAS program lines for analysis of data within and between time periods (SAS Institute 1988).

Comparison	Experimental design	SAS program lines
Within a time period	Completely randomized design	Proc glm; by date; class tmt; Model bugs=tmt; means tmt/regwq;
Among time periods	Split plot in time	Proc glm; class apt date tmt; Model bugs=apt date apt*date tmt date*tmt; means tmt/regwq;
Among time periods	Regression for each treatment	Proc glm; by tmt; Model bugs=week/p clm;

CONCEPTS IN EXPERIMENTAL DESIGN: CONCLUSIONS

Prior to conducting field trials, we must consider the goals of the project and the experimental design. Any field experiment should have an untreated control or consistent standard for comparison. If treatments are different from each other yet not different from the control, then the treatments were all ineffective. Based on the spatial distribution of cockroaches in apartments, the number of apartments necessary for the smaller differences among treatments than with comparisons within time periods. In addition, more information, such as population growth rate, can be obtained with this approach. Comparisons of treatments are somewhat more difficult and we lack good mathematical model with which to fit our data.

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The goal of this paper has been to outline some of the biological and statistical realities that we are faced with in field testing insecticidal products against German cockroaches. However, our expectations for German cockroach control must also be reexamined because our experimental designs will reflect these expectations. Even though we wish to emphasize the pest management theme, in the field crop sense, management implies keeping pest numbers down below an economic threshold. Some pests always remain. We do not believe management, in this sense, is appropriate for German cockroaches in homes and commercial kitchens. Our state health departments apparently believe the same since the presence of one cockroach is a violation of the health code. Perhaps our real goal is elimination or eradication rather than management. Our goal should be 100% reduction.

Assuming eradication is the goal, are significant differences among treatments that do not control populations meaningful? What is a meaningful reduction that is less than 100%? It is in this context that the researcher must judge biological or practical significance versus statistical significance. It must be kept in mind, however, that if lower mean numbers are obtained, then more traps or apartments are necessary (by rearrangement of Reusink's sample size equation) to estimate means at the same accuracy.

How long should field efficacy studies run? Most researchers trap at 1, 2, 4, 8, and 12 wk after treatment, but is it reasonable to expect any treatment to work for three months in the hostile environment of public housing? Most professional pest control operators visit accounts monthly. If control has not been achieved an additional treatment is applied. Many conventional treatments have the best results at one month, then populations increase. Should a relevant time period for field efficacy trials be 30 days? Obviously, IGR treatments should run longer, but how much longer? The locations that we conduct field efficacy trials are invariably low income public housing. We use these apartments because they have many cockroaches, but are these realistic models for defining expectations of product performance? We assume that if a treatment is ineffective in the public housing environment then it must be ineffective in other situations. There have been no studies to support this assumption.

In conclusion, we have discussed some of the important biological, ecological, and statistical considerations that must be accounted for in insecticide field efficacy studies. Better and more accurate data can be obtained by minimizing variance. We must design our experiments with a thorough understanding of the target pest and realistic goals.

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TERMITE DISTRIBUTION, COLONY SIZE, AND POTENTIAL FOR DAMAGE

J. Kenneth Grace

Department of Entomology
University of Hawaii
3050 Maile Way
Honolulu, HI 96822-2271

ABSTRACT *Coptotermes formosanus* Shiraki, *Heterotermes aureus* (Snyder), and *Reticulitermes flavipes* (Kollar) are extremely important economic pests in North America and Hawaii. In the past decade, mark-release-recapture studies using dye markers have resulted in much larger estimates of the foraging populations in colonies of these termite species than had been suggested by earlier studies using direct sampling methods. Colonies containing from several hundred thousand to several million termites can forage over an area exceeding 3,000 m^2. Foraging worker biomasses up to 34 kg have been reported, and a colony of this size would consume approximately 1 kg of wood each day. The results of these studies indicate that many structures within the vicinity of a discovered subterranean termite infestation are likely to be at risk, and confirm that localized spot treatment with soil termiticides within infested structures is not appropriate for subterranean termite control. Baiting systems could effectively reduce colony populations, but will require monitoring of colony foraging activity after treatment.

Keywords - *Coptotermes formosanus*, *Heterotermes aureus*, *Reticulitermes flavipes*, subterranean termites, Rhinotermitidae, baits

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There are approximately 2,200 known species of termites (Isoptera), most of which are found only in the tropics (Wood and Johnson 1986). In Hawaii and North America, although drywood termites (Kalotermitidae) are serious structural pests, the most economically important pests are the subterranean termites *Coptotermes formosanus* Shiraki, *Heterotermes aureus* (Snyder) and *Reticulitermes* spp. (Rhinotermitidae) (Weesner 1965; Mauldin 1986). The Formosan subterranean termite, *C. formosanus* is a worldwide problem in the tropics and subtropics, and is found in Hawaii, portions of the southeastern United States (Su and Scheffrahn 1990), and (very recently) the southern California coast (M. K. Rust, pers. commun.). *Heterotermes aureus* is limited to the desert regions of southern Arizona, California, and Mexico, while *Reticulitermes* spp. represent the most broadly distributed termite genus in North America (Weesner 1965). The eastern subterranean termite, *Reticulitermes flavipes* (Kollar), is found throughout the southeastern United States, north along the Atlantic coast into Maine, and west along the shores of the great lakes into Ontario, Canada (Weesner 1970). Transported infestations of this species have become established as far north as Winnipeg, Manitoba (Anonymous 1989).

These North American subterranean termites nest in the soil, and their galleries do not incorporate mounds or other nest structures that are separable from the surrounding soil matrix. This presents obvious difficulties in studying colony demographics and foraging dynamics. In the past decade mark-release-recapture (or capture-recapture) methods using a fat-soluble dye, have proven extremely useful in studying colony population sizes and foraging territories of the three principal North American subterranean termite genera.

DIRECT METHODS OF POPULATION ESTIMATION

Direct, destructive sampling has been used to measure the population of mound-building termite colonies (e.g., Darlington 1984). Howard *et al.* (1982) used excavation, followed by exhaustive trapping with corrugated cardboard, to census *R. flavipes* colonies living in stumps in rural Mississippi. Their estimate of an average *R. flavipes* colony population of ca. 245,000 termites was, until very recently, the most authoritative and frequently cited estimate available for this serious structural pest. However, since the common North American subterranean termites generally do not have a well-defined nest structure, total gallery excavation is a formidable task, and certainly not possible in densely inhabited urban areas. Loss of insects in the process of collecting and processing such large quantities of soil is also a problem.

In open range-land, extraction of termites from soil cores has been used to estimate population density (Uekert *et al.* 1976), although not discreet colony populations. This method is impractical in urban situations, since neither subterranean galleries nor the insects themselves are likely to be distributed homogeneously over a given area.

Sequential removal of termites in cardboard baits was used by Ewart (1988) to estimate the populations of *Coptotermes lacteus* (Froggatt) mounds in Australia. Although less intrusive than excavation or soil cores, this is also a destructive sampling method, and best suited to fairly small populations where the number of foragers captured will decline rapidly in sequential captures.

Foraging intensity, or the amount of cellulosic food material removed per unit of time by termites in a given area, offers a simple method of estimating the change in size of a foraging termite population, after a bait application for example (e.g., Ostaff and Gray 1975; Jones 1988). However, estimation of true population size is not practical, unless one is actually able to measure termite feeding on all the available food resources. In all likelihood, though, this is the method that will be adopted by pest control operators to determine the success of termite baiting operations, because of the speed and simplicity of placing and monitoring wooden stakes or baits at a given site. The responsibility will lie with researchers to supply the pest control industry with at least "rule of thumb" correlations between feeding intensity and forager numbers.

A difficulty in applying any of these direct methods of population estimation to North American subterranean termite colonies is that one must either have prior knowledge of the distribution of individual colonies in the study area, or make critical (and untestable) assumptions about that distribution.

DIRECT METHODS OF TERRITORY MEASUREMENT

Methods of measuring subterranean termite foraging territories were discussed by Jones (1988a) in an address to the second National Conference on Urban Entomology. Excavation of termite galleries, spatial patterns of attack on natural vegetation or bait grids, and bioassays of agonistic interactions among conspecifics from different sites have all been used to estimate territory sizes. King and Spink (1969) excavated a *C. formosanus* colony in Louisiana and determined that the galleries extended throughout an area of approximately 5,650 m^2, a figure that has been supported by later mark-release-recapture studies. Haverty *et al.* (1975) estimated the average size of *H. aureus* foraging territories as 12.5 m^2 from the patterns of attack on baits placed in a large grid, but later mark-release-recapture studies by Jones (1990b) demonstrated that this type of analysis greatly underestimated actual territory sizes.

MARK-RELEASE-RECAPTURE STUDIES

Radioisotopes have been used in several studies to measure subterranean termite foraging territories (e.g., Li *et al.* 1976; Spragg and Paton 1980). However, histological dyes have proven to be the most useful and popular tools for marking termites. Studies using these dyes to mark *C. formosanus*, *R. flavipes*, and *H. aureus* have, in the past decade, generated dramatically different sociometric data than had been previously assumed, or suggested by direct sampling methods.

The use of dyes to mark subterranean termites appears to have originated independently during the early 1970's with two well-known termite researchers: Frances M. (Weesner) Lechleitner at the University of Colorado, and Minoru Tamashiro at the University of Hawaii. To date, the record of Lechleitner's work with dyes is limited to unpublished reports (c.f., footnote in Esenther 1980). Tamashiro's work in this area had greater impact through his publications with his students, and the independent contributions of those students.

A prerequisite to the use of dyes is an efficient and nondestructive method of collecting (and recollecting) termites from the soil. In the dry southwest, grids of toilet paper rolls placed on the soil surface proved effective with *H. aureus* and other desert termites (La Fage *et al.* 1973), while small wooden boxes, each placed over a stake and contained within a metal can placed on the soil with the bottom cut out, were used in Hawaii to collect *C. formosanus* (Tamashiro *et al.* 1973). Su and Scheffrahn (1986) modified the Hawaiian trap design so that traps could be hidden from sight in public areas of urban Florida. Grace (1989a) further modified this design to improve captures of *R. flavipes* in Ontario, Canada, and this design has also proved effective for collecting large numbers of *Reticulitermes hesperus* Banks workers in California (J. Smith, pers. commun.). In addition to wood, these later designs incorporated the use of corrugated cardboard, which had been described by Esenther (1980) and La Fage *et al.* (1983) as an excellent substrate for collecting subterranean termite foragers. Recently, Ewart *et al.* (1992) recommended a simple modification (a drill hole) of the wooden stakes usually used to locate termite field sites, in order to facilitate subsequent installation of collection traps without disrupting the termites' foraging galleries.

Dyes were first used in Hawaii to measure the distance travelled by *C. formosanus* workers, fed filter paper impregnated with Fast Green, between interconnected traps (Fujii 1975). The maximum distance thus measured of 160 feet (Fujii 1975) was very close to the distances of 165 feet (Ehrhorn 1934) and ca. 200 feet (King and Spink 1969) reported from destructive excavations of Formosan subterranean termite galleries. Subsequently, Lai (1977) and Lai *et al.* (1983) screened nine histological dyes and identified Sudan Red 7B as the most persistent and least toxic dietary dye marker for *C. formosanus*. In addition to measuring termite foraging distances (110 m), Lai (1977) was the first researcher to use the simple Lincoln (1930) index, based on the ratio of marked to unmarked workers in the recaptured sample, to estimate the foraging population of three *C. formosanus* colonies at 1.3-1.6 million. Su (1982) and Su *et al.* (1984) applied Lai's (1977) technique to estimate *C. formosanus* colony populations as high as 4.4 million, and, more importantly for the validity of the method, demonstrated that foraging termite workers did not show fidelity to any particular feeding site. Su *et al.* (1983a, 1983b) also refined Lai's (1977) application dosage and demonstrated that Sudan Red 7B was not passed in detectable quantities by trophallaxis.

As is illustrated by the citations above, Sudan Red 7B has been the subject of a fairly large number of methodological papers. Su *et al.* (1988) further refined the dose/time relationship for effective marking of *C. formosanus*, and found that this dye was not appropriate for marking *R. flavipes* with the 41-day release-recapture cycle used by these authors (Su and Scheffrahn 1988a, 1988b). However, Grace and Abdallay (1989) demonstrated that Sudan Red 7B could safely be used with shorter (ca. 3 week) release-recapture cycles with *R. flavipes* (Grace 1989, 1990; Grace *et al.* 1989). Sublethal effects of Sudan Red 7B on *C. formosanus* were found by Delaplane *et al.* (1988) and Delaplane and La Fage (1989), who confirmed Lai's (1977) observation of reduced gut protozoan populations, and also attributed a slight but significant decrease in termite feeding to dye exposure.

The dye Neutral Red was used by Esenther (1980), who attributed the dye method to Lechleitner, to mark *R. flavipes* workers and estimate the size of termite colonies in Wisconsin. Although these were the first such estimates for *R. flavipes* colonies, they had little impact due to the large standard errors of the estimates, and limited distribution of his report (Esenther 1980). Grace *et al.* (1989) subsequently confirmed Esenther's (1980) observation that *R. flavipes* colony populations could number into the millions, with lower standard errors associated with these authors' estimates.

Neutral Red was also identified by Salih and Logan (1990) as the most promising of 30 dyes tested as markers for *Microtermes lepidus* Sjostedt. The search continues for additional dye markers, to use either singly or in combination (e.g., Grace and Abdallay 1990). Recently, Su *et al.* (1991) identified Nile Blue as a safe and persistent marker for *R. flavipes*.

So long as the dye marker is readily recognized, mark-release-recapture methods provide a definitive measurement of subterranean termite foraging distances (the distance between release and recapture trap sites) and, with an adequate distribution of traps throughout the site, foraging territory areas. In urban areas where field sites are always constrained by pavement, buildings, fences, and other obstructions, these distances and territory sizes generally represent minimum values since the actual territories may well extend beyond the boundaries of the site.

Population estimates from mark-release-recapture studies are somewhat less definitive, since the validity of the Lincoln index estimate is contingent upon certain assumptions (Southwood 1978): (1) marked animals are not affected in behavior and life expectancy, and marks will not be lost or transferred; (2) marked animals become completely mixed in the population; (3) the probability of capturing a marked animal is the same as that of capturing any member of the population; (4) sampling must be at discrete time intervals; (5) the population is closed; (6) there are no births or deaths in the period between sampling. Although Su *et al.* (1984) established that *C. formosanus* foragers show no allegiance to specific foraging sites, assumptions (2) and (3) are difficult to demonstrate in practice and are usually dealt with simply by placing a large number of traps throughout the study area.

COLONY POPULATIONS AND FORAGING TERRITORIES

Prior to the use of mark-release-recapture methods, the best estimates of North American subterranean termite colony populations derived from direct sampling methods were as follows: *C. formosanus*, 450,000 (Nakajima and Mori 1961, cited in Su and Tamashiro 1987); *H. aureus*, 22,632 (Haverty *et al.* 1975); *R. flavipes*, 244,445 average with a range of 51,505 - 363,512 (Howard *et al.* 1982).

Mark-release-recapture studies have revised all of these estimates to reflect much larger colony sizes: *C. formosanus*, 1.4 - 6.9 million (Su and Scheffrahn 1988); *H. aureus*, 45,000 - 300,000 (Jones 1987, 1990a); *R. flavipes*, 0.72 - 3.2 million (Grace *et al.* 1989; Grace 1989, 1990). Very large foraging territories have also been measured in these studies: *C. formosanus*, 3,571 m^2 (Su and Scheffrahn 1988); *H. aureus*, 3,316 m^2 (Jones 1987, 1990b); *R. flavipes*, 1,091 m^2 (Grace *et al.* 1989). These revised estimates do not, of course, mean that all termite colony populations or territories are these sizes, but they certainly demonstrate a greater potential for colony growth than had been considered possible based upon the earlier estimates.

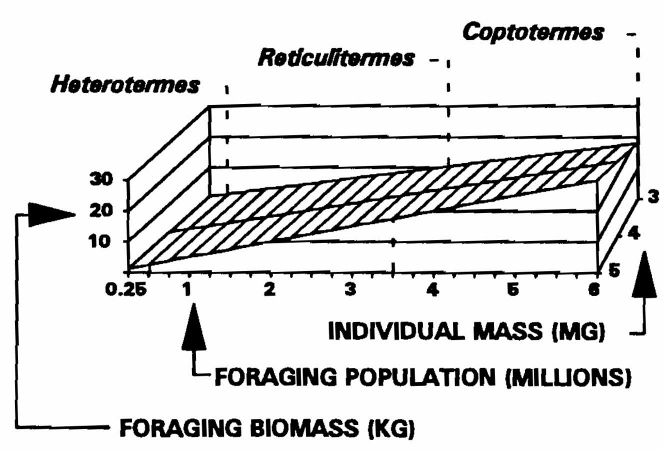

FIGURE 1. Estimated foraging biomass of colonies of *Heterotermes aureus*, *Reticulitermes flavipes*, and *Coptotermes formosanus*, based on the weight of individual workers and current published estimates of the size of colony foraging populations (see text). Dotted lines indicate the approximate range for each termite species.

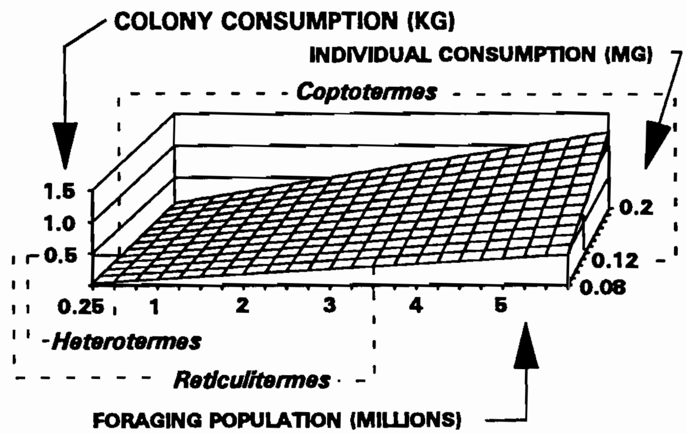

FIGURE 2. Estimated daily wood consumption by active colonies of *Heterotermes aureus*, *Coptotermes formosanus*, and *Reticulitermes flavipes*, as a function of the daily consumption of individual workers and the estimated foraging population. Dotted lines indicate approximate consumption range for each termite species.

POTENTIAL FOR DAMAGE AND IMPLICATIONS FOR CONTROL

With termite colony populations extending into the millions, the foraging biomass of an individual colony (superorganism) can be considered equivalent to a large grazing animal. The *R. flavipes* colony foraging populations measured by Grace *et al.* (1989) represented foraging biomasses of 7 -10 kg, and the *C. formosanus* colonies studied by Su and Scheffrahn (1988) were between 4 - 34 kg. Figure 1 represents termite foraging biomass as a function of the foraging population and the average weight of individual workers, with the approximate cut-off points for each termite genus based upon current mark-release-recapture information.

Although feeding may be spread over several thousand square meters, a large *R. flavipes* colony will ingest almost 0.5 kg of wood each day, while a large *C. formosanus* colony could consume twice that amount (Figure 2). Individual subterranean termite colonies thus present a grave threat to wooden structures within their foraging territory. From the point of view of termite control, the large size of these foraging territories certainly confirms that spot-treatment (application of soil termiticide in a localized portion of the infested structure) for these subterranean termites is not practical. Moreover, structures (or other wood in service) in the vicinity of an infested building should be considered at risk, and a pest control operator would be quite justified in promoting inspection of such buildings.

Baiting systems using baits, dusts, or microbial pest control agents for subterranean termite control may well be implemented in the near future, and mark-release-recapture studies are absolutely essential in bait development to demonstrate efficacy and refine application methods (e.g., Su 1991). Because bait placement will be critical to the success of this method, pest control operators will have to monitor the site after bait application much more rigorously than has been the case with soil treatments. However, it is unrealistic to expect that pest control operators will be prepared to conduct mark-release-recapture studies in conjunction with bait applications. Pest control operators will likely place small wooden stakes or their equivalent, and monitor termite population suppression by the decline in feeding on these stakes.

Practical application by pest control operators of baiting systems for subterranean termite control will probably follow this sequence:

(i) Pre-bait to identify locations for bait application. This may be less necessary in or around structures where infestation is quite visible. However, pre-baiting techniques such as hollow stakes (Ewart *et al.* 1992) may also be very useful in applying baits without interfering unduly with termite foraging galleries.

(ii) Apply baiting system. Bait stations may contain an oral toxicant, a toxic dust or other topical formulation, or a microbial agent. Aggregation traps for mass trapping, followed by treatment with a toxicant and release of the treated individuals, might also be effective (although labor-intensive) in some situations (Grace and Abdallay 1990; Myles and Grace 1991).

(iii) Monitor termite foraging intensity during and after treatment with stakes or other monitoring technique.

(iv) Continue to use a monitoring method (stakes) along with periodic property inspections as part of a continuing service contract.

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BAITS AND BAIT TECHNOLOGY

Donald A. Reierson and Michael K. Rust

Department of Entomology
University of California
Riverside, CA 92521

ABSTRACT - Food and contact baits are most efficacious against specific eusocial and communal insects. Long-range attraction to bait, recruitment and trophallaxis improves bait performance. Environmental (abiotic) and biological (biotic) factors interact simultaneously to affect German cockroach bait efficacy. Cockroach bait performance increases as refugia and competitive food decrease, and as the number of bait placement sites increase. If used in conjunction with bait, residual insecticides should be used carefully to minimize repellency. Cockroaches may learn to avoid successive sublethal contact with bait. Magnified by learned avoidance, low levels of insecticide resistance may be sufficient to allow control failures and resurgence of populations.

Keywords - Bait, Cockroach, *Blattella germanica* (L.), Attraction, German cockroach, Learning.

A few selected species of household, commercial and peridomestic insect pests can be controlled with bait, but most cannot. Theoretically, the continual presence of an acceptable active bait should lead to the elimination of the target pest population, but that rarely happens. Under best conditions bait usually provides temporary population reduction. The use of bait indoors appears to have greatest utility in specialized situations where application of insecticidal liquids or dusts are precluded, and where chemical odor must be avoided.

Baits are generally thought of as mixtures of insecticide and an attractive food substance that provide effects after insects eat them. It is presumed that insects attracted to the food component succumb after they ingest portions of the mixture. "Contact baits," however, act through direct surface contact and do not necessarily need to be ingested in order to provide an effect. A common theme of control with bait has been that insects are attracted to the bait over relatively long distances, and that insecticides with slow action are more effective in baits than are fast-acting toxicants.

Rust (1986) indicated that only a few urban household insect pests may be susceptible to baiting technology (Table 1). Bait sensitivity may be related to degree of sociability, the efficacy of bait being greatest for insects which recruit other members of their population to acceptable food they locate. For example, bait works particularly well against some species of ants because foraging workers which find suitable bait communicate the location and appropriateness of the bait to other workers, which results in greater uptake of bait into the colony. Besides recruitment, eusocial insects such as ants, yellow jackets and termites exchange alimentary liquid among colony members. This exchange is called trophallaxis and may result in the passage of insecticide-laden food from one member of the population to others. Trophallaxis may ensure dissemination of bait among queen, workers and brood. Death of the queen or lack of adequate brood care may result in havoc and the demise of a social colony. There is evidence that trophallactic exchange occurs among cockroaches, but it is not clear that it is sufficient to provide significant effects from bait.

TABLE 1--The reported efficacy of baits against household insect pests.

Group	Pest	Efficacy
Cockroaches	*B. germanica*	++++
	P. americana	++++
	B. orientalis	++
	S. longipalpa	?
	P. fuliginosa	?
Ants	*I. humilis*	++
	M. pharaonis	++++
	(*Solenopsis spp.*)	++++
	(Crazy, pavement, little black, odorous, thief, etc)	?
Crickets	(*Gryllus*; *Acheta*)	++
Miscellaneous	(Termites)	?
	(Flies)	?
	Fleas	No
	Spiders	No
	Fabric pests	No
	Mites, ticks, etc.	No

Adapted from Rust, in Adv. Urban Pest Management. (1986)

Communal insects (Wilson 1971) such as some species of cockroaches exhibit intermediate vulnerability to bait. For the German cockroach, *Blattella germanica* (L.), this intermediate susceptibility may be related to limited foraging from strong aggregations in protected refugia, provided the cockroaches have ready access to food and water. In addition, cockroaches are not consistently attracted over long distance to any food substance. Although bread, stale beer (perhaps a lactic acid component), banana, and moisture may under some conditions attract cockroaches over a distance of a few inches, it is presumed that cockroaches usually locate food fortuitously, by chance encounter. Cockroaches tend to feed vigorously on food containing carbohydrates such as starch, sucrose or glucose, but highly proteinaceous food slows feeding. Most insects, including cockroaches, respond strongly to water if they are dehydrated, but will show little or no interest in water as an attractant if they are satiated. Because of limited trophallaxis among communal insects, the effectiveness of bait against pests such as cockroaches, depends primarily upon individual insects locating and eating it. Individual cockroaches may temporarily or permanently leave refugia and eat bait they encounter. In the case of cockroaches, bait near aggregations has the greatest opportunity to provide kill because cockroaches will feed on the nearest acceptable food.

For most communal or solitary insects, factors that increase foraging increase the likelihood of them finding bait. Because insects moving in response to stress do not necessarily feed, increased movement, *per se*, does not assure increased bait consumption. Insects such as crickets, earwigs and peridomestic cockroaches, however, become vulnerable to food and baits as the insects move in response to crowding or adverse environmental condition. The foraging activity of most domicillary cockroaches increases with crowding, when deprived of food or water, or when exposed to excessively high temperature.

Food searching behavior may be reinforced by chemical or optical cues and through learned response. Some insects have stylized foraging behaviors that can be taken advantage of with bait. For instance, the exceptionally strong tendency of some species of carpenter ants and cockroaches to forage along edges may be exploited by placing baits along paths most likely to be taken by the pest. Bait close to aggregations or positioned so that encounters with the bait are maximized usually results in best control. Because of the lack of attraction, most cockroach baits should theoretically perform about as well as very efficient traps. In this regard, traps placed just 1 or 2 inches from an intersection capture only about 10-50% as many cockroaches as when they are placed directly at an intersection.

The response of solitary insects to bait is more variable, bait generally not being the treatment of choice for these insects. Some flies, moths, and beetles respond fairly long distances to certain odors and colors and are therefore vulnerable to special odoriferous contact baits. The insects are killed when they alight on a toxicant-laden substrate from which the odor emanates. Most solitary and communal structural arthropod pests such as fleas, pantry pests, beetles, spiders, mites, and phytophagous pests do not respond to food attractants and are unaffected by baits.

The purpose of this presentation is to provide a brief overview of the concepts, status of baiting and bait technology for urban insect pests, with special reference to factors that affect control with bait. Most of our observations and interpretations are based on research we have conducted at UC Riverside, but it should be born in mind that a great deal of research has been conducted elsewhere regarding the physiology, behavior and ecology of urban pests, and that the effect of bait on each pest must be studied and considered independently. We have confined most of our remarks to the response of the German cockroach, *B. germanica*, to bait.

GENERAL USEFULNESS OF BAIT FOR URBAN INSECT PESTS

Peridomestic insects and occasional invaders.

Baits can be used to prevent peridomestic and occasional invading pests from gaining entry to buildings. The insects die as they cross the barrier. They do not necessarily have to eat the bait for it to be effective, but some may do so. We have used barriers of Baygon 2% granular bait around structures many times to control localized problems of migrating field crickets, earwigs, cockroaches and ants. Baits also have been used to reduce the number of scorpions, pill bugs, and sow bugs around structures. Migrants encounter the barrier when they move towards structures when they forage or seek new shelter as their habitat dries. Baygon bait is also effective against the oriental cockroach, *Blatta orientalis* L., and the smoky-brown cockroach, *Periplaneta fuliginosa* (Serville), especially if the bait is scattered in specific resource sites where the insects eat, travel or reside.

Ants.

There is wide variation in the responsiveness of ants to bait, the variation probably being related to the natural foods on which the ants are foraging. Some important pest species can be controlled with bait, at least within a limited geographical area. Effective baits for ants require a precise combination of a palatable food base and an effective non-repellent toxicant. There is a great deal of interest in developing a universal bait for ants, but that goal may be unattainable. Although it seems simple to mix carbohydrates and proteins into an effective ant bait system for sweet-eating, predaceous, and scavenging species, such an effective combination has not been found. Most attempts at universal ant baits have met with dismal failure.

Colonies of the red imported fire ant, *Solenopsis invicta* Buren, around homes can reportedly be eliminated with granular AMDRO[R] hydramethylnon bait placed close to the colony. Foraging ants seize particles of the bait amazingly quickly and take it into the colony where it is incorporated via trophallaxis. Similar good results have been claimed for FIRE ANT ENDER avermectin B_1 bait. We have obtained excellent control of the closely related southern fire ant, *S. xyloni* McCook, with a proprietary hydramethylnon bait composed of dry insect fragments, but neither standard AMDRO[R] or the avermectin bait worked well. Specificity of ant bait is apparently related to the palatability of the bait base, and ultimate acceptance is also related to active ingredient. The proprietary hydramethylnon bait we tested that worked so well against *S. xyloni* was not fed upon by sympatric species such as the pyramid ant, *Dorymyrmex pyramicus* (Roger), probably because the bait was primarily proteinaceous rather than carbohydrate. Similarly, harvester ants, *Pogonomyrmex spp.*, readily picked up particles of protein bait containing avermectin but were unaffected by it. The ants brought the bait back to the surface the following day, placing it in discard piles a few inches from the nest entrance. It appears that ant bait formulations must be tested against each target species for which the bait is intended, and that the bait should probably be evaluated over the entire season or developmental period in which the ant occurs.

Labor-intensive baiting with fresh liver mixtures adulterated with insect growth regulator reportedly provides good control of pharaoh ants, *Monomorium pharaonis* (L.), but control is usually achieved over a period of several weeks to several months. It is only in the last few years that *M. pharaonis* has become a serious and important pest in California, but it has been a significant pest elsewhere for many years. Until baits were developed to control them, pharaoh ants were nearly impossible to eliminate, even from a small area. Once the ant is established, insecticide sprays may kill some of the ants but colonies "bud" in response to the spray and the problem usually worsens and widens. We have achieved excellent control of this ant within a week in apartments with as few as 6 strategically placed stations of a PHARAOH ANT KILLER hydramethylnon bait placed mostly in kitchens and bathrooms where the ants had been seen. Similar good pharaoh ant control has been claimed for bait containing 0.5% sulfuramid, but we have not had consistently good results with it.

Yellowjackets.

Bait provides one of the best methods for controlling scavenging yellowjackets, such as the western yellowjacket, *Vespula pensylvanica* (Saussure) (Wagner and Reierson, 1969). Fish-flavored pet food adulterated with microencapsulated diazinon (Knox-Out 2FM) provides good control over wide areas. Synthetic attractants such as heptyl butyrate, heptyl crotonate, and hexyl isovalerate have been used to lure yellowjackets to the vicinity of the bait. The synthetic attractants mimic components of cooked or rotting meat. Bait is carried to the colony by worker yellowjackets and control is achieved as bait is fed to the larvae. Once found, the bait is fed upon by other yellowjackets recruited to it. Insect growth regulators, novel insecticidal compounds such as photodynamic dyes, and biologicals such as nematodes may have promise in baits for this specialty problem. Yellowjackets feeding on sweet liquids or preying on live insects are not affected by bait.

COCKROACH BAITS: DISCREPANCY BETWEEN THEORY AND RESULTS

The German cockroach remains one of the most widespread household and commercial insect pests of the United States. We documented the presence of *B. germanica* in 66% of restaurants we surveyed in southern California (Los Angeles county), even though all the surveyed restaurants were currently being regularly serviced by a professional pest control company. As found almost everywhere else, the German cockroach is particularly common and troublesome in commercial buildings where food is prepared and served on a regular basis, and in low-income homes and apartments where there is poor sanitation and construction deficiencies that provide a predonderance of cracks, crevices and refugia. Under conditions of minimal immigration effective bait should be capable of eliminating a specific insect population. That is rarely the case with the German cockroach.

Excellent results obtained with a few strategically placed hydramethylnon baits just a few years ago are apparently no longer being achieved on a regular basis. Eight years ago, based on trap catch, we reported 90 to 100% reductions of *B. germanica* in single-floor, 500ft^2 apartments treated with just 12 stations of 1.65% hydramethylnon bait. Similar reports of good control at that time were made by others elsewhere. Recent reports, however, are less optimistic. Regardless of the active ingredient, recent studies rarely indicate the excellent level of control that was achieved previously. It is customary now in low-income apartments to document <50% reductions with recommended rates of application of discrete stations of bait containing boric acid, chlorpyrifos, hydramethylnon, or sulfuramid. Better reported results for directed avermectin baits may be related to the greater number of sites in which the bait is installed.

ABIOTIC FACTORS THAT IMPROVE THE SUCCESS OF BAIT

Factors that affect cockroach baiting probably also affect nearly every other urban insect bait target pest.

Good sanitation

Sanitation may have an indirect and a direct effect on bait performance. The number of cockroaches per infested area appears to be related to the amount of undisturbed dark harborage available to them, provided adequate food and water are nearby (Fig. 1). In instances of very large populations, less-preferred secondary harborages in the open become inhabited by emigrants from primary harborage. Crowding reduces successful mating and elicits aberrant behaviors such as cannibalism of immatures and other stages, especially at the time they moult. Cockroaches in secondary harborages are more vulnerable to bait because

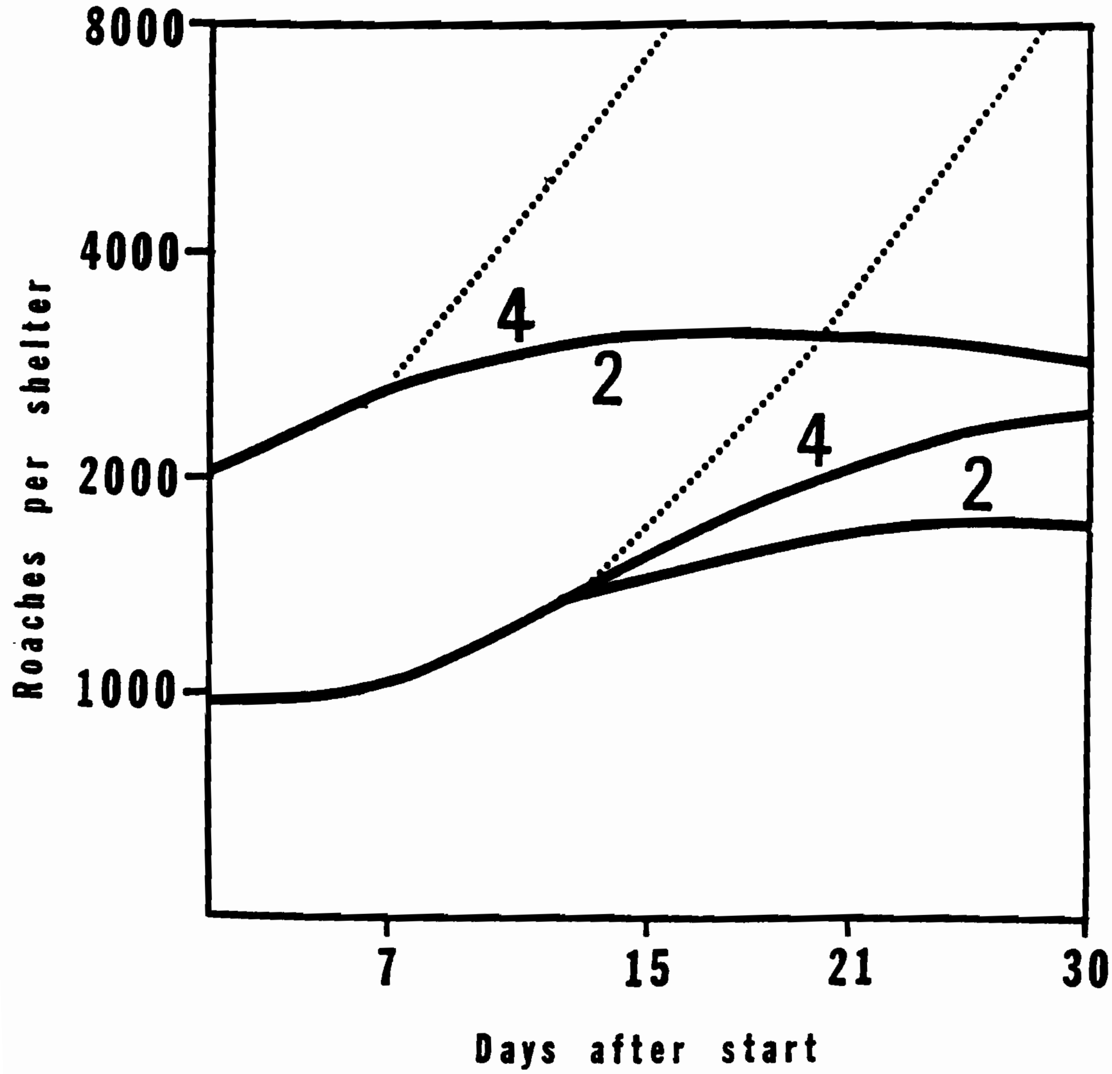

Fig. 1 Growth of a population of *B. germanica* in the laboratory where food and water were not limited. Started with 1,000 and 2,000 cockroaches (50% adults). Two or 4 one-quart shelters provided each population. Dotted lines indicate theoretical increase; solid lines indicate actual numbers.

they move more in search of better conditions. Excessive clutter provides refugia in which cockroach populations can expand. By reducing clutter, on the other hand, populations are limited by the physical characteristics of their surroundings and the number of sites necessary for bait treatment are decreased. Once established in an area, cockroach populations increase if items such as paper bags, newspapers, piles of clothing, stored items, and unused furniture accumulate. We often see hundreds of cockroaches in unused stoves and other appliances, in piles of paper bags, in mops and brooms, in kitchen drawers used for storage, etc. Unnecessary clutter should be eliminated.

Reduced amounts of competitive food

Food deprivation is a more direct component of an improved sanitation program than is removal of clutter. Bait palatability and acceptance is extremely important for good control with bait. The presence of competitive food nearly always reduces bait efficacy. Conversely, absence of competitive food always improves bait performance. Not only do cockroaches feed irregularly (especially females with oothecae), but they may repeatedly return to sites where there is acceptable food and shun new food placed in their surroundings. Elimination of competitive food enhances bait performance by having only bait available when the cockroaches forage. In addition, movement from aggregations increases as food supplies diminish.

Partially starved cockroaches search for food vigorously. Cockroaches deprived of food for even a day or two respond quickly and more positively to palatable bait than when they are well fed (see Table 2). Satiated cockroaches show much less interest in bait and are more discerning as to the food they eat. Perhaps this is why bait tends to perform well in clean or vacant apartments, and in commercial establishments where a concerted effort has been made to clean up on a continuing basis. Although it is difficult to eliminate enough available food in household settings (on the average, a cockroach eats only about 1 to 3 milligrams of food per day), laboratory trials show that reducing the amount of food available to cockroaches significantly improves bait efficacy.

TABLE 2 -- Effect of starvation on the performance of bait against adult male *B. germanica*.

BAIT	Food & Water	NO FOOD 24 hr.	NO FOOD 48 hr.
Combat	63.3	64.0	100
Baygon	28.0	92.0	100

4 Chambers of a olfactometer

Proper bait placement

Bait efficacy increases as the number of bait placements increase. There is probably a number of placement sites above which control will not improve but, regardless of active ingredient, most consistent results were obtained where we used about 24 strategic bait placements per apartment kitchen (approximately 1 placement per 4 ft^2 of floor area). Bait is most effective when installed along intersections and in cracks and crevices near where cockroaches reside. Each situation must be evaluated independently, but it should be born in mind that cockroaches are not attracted over distance to food substances and that control with bait usually improves in direct relation to the number of critically placed stations that are used. We have observed large numbers of cockroaches living close to bait. In one instance we found over 50 of them in a corner of a kitchen cabinet within 12 inches of bait, indicating the poor attraction capability of bait. The insects were killed when the bait was moved closer. The good control reported with AVERT avermectin bait may be at least partly attributable to very high numbers of bait placements (100-200) recommended near areas of infestation.

Moisture

Cockroaches are particularly vulnerable to desiccation and they require water for survival. Most commercial baits are dry baits, but reports in the literature suggest that moist baits may be more effective, especially if the target population is under any kind of water stress. Gels and paste baits are apparently very effective (Appel and Sponsler 1990), probably because those formulations contained water. Even after they dry out, some moist baits remain insecticidally active if cockroaches eat them. This has been found for various boric acid baits. Because cockroaches often aggregate close to sources of water, bait placed near water may be more effective than if placed far away. Appel (pers. comm.) suggests that sublethal exposure to pyrethroid insecticide may inhibit cockroach movement to such an extent that the cockroaches become partially dehydrated and that "thirsty" cockroaches that recover from the insecticide might be particularly vulnerable to moist bait.

ABIOTIC FACTORS THAT REDUCE THE SUCCESS OF BAIT

Clutter and inaccessible harborages

Just as reduced clutter improves the performance of bait by limiting harborage, increased amounts of clutter provide refugia in which cockroaches can live and develop. Stacks of stored items, clothing, parts of furniture, and voids may provide harborage in which thousands of cockroaches may develop within a very confined area. These places are often particularly difficult to treat with containerized bait. Paste baits and directed baits may be more effective in these special situations. Where possible, it is best to reduce clutter simply by removing it.

Insecticides

It is generally accepted that residual insecticides interfere with the performance of baits. This has been well documented with ant baits. As reported by Haack and Granovsky (1990), we were unable to control pharaoh ants with bait in apartments where sprays were applied simultaneously. We have had similar poor control of Argentine ants when we tried to bait them after sprays were used to eliminate workers. There is no clear evidence, however, that residual sprays have a negative impact on the effectiveness of cockroach baits. Repellent insecticide, such as pyrethrins and pyrethroids, applied on a bait station or in its vicinity is likely to render the station repellent. In addition, incomplete application of spray allows cockroaches to move to untreated secondary refugia. Large secondary populations can develop unless bait is available near those refugia.

Insecticide applied in specific sites may have little effect on bait in another site. Spray and bait may be compatible within the same structure, provided they are some distance from one another. Cockroaches in peripheral sites may be reduced without affecting populations in primary harborages.

As mentioned previously, there is also the intriguing possibility that some insecticides may actually improve the performance of bait by preventing movement or feeding long enough to cause cockroaches to be "starved" and to then respond more vigorously to bait that they ordinarily would. It is presumed that such insecticide should not be sprayed directly onto bait stations or in the immediate vicinity of loose bait.

BIOTIC FACTORS THAT IMPROVE THE SUCCESS OF BAIT

Palatability and bait acceptance

Except for a few contact baits, cockroaches must consume bait for the bait to be effective. Increasing the rate of feeding on bait increases speed of kill (Tsuji and Ono 1970). Depending on sex and stadia, German cockroaches on the average eat about 1 to 3 milligrams of food per day. Once they contact it, factors such as excessive surface oiliness, rancidity, dust, and the presence of mold or fungi may greatly diminish the likelihood that cockroaches will eat the bait. We observed total inhibition of feeding of the American cockroach, *P. americana* (L.), on boric acid baits in sewer shafts when mold and fungus developed on the bait. Feeding was reinstilled when we presented bait to the cockroaches after we removed the growth of fungus covering the bait. We have observed similar repellency behaviors for *B. germanica* when water wicks in cockroach cultures were covered with fungus or mold. Even highly desiccated cockroaches reduced their drinking until a clean drinking surface was made available to them.

Repellent active ingredient or other chemicals can also reduce palatability. It has been suggested that reduced effectiveness of recent baits in comparison to older ones may be related to new and "improved" formulations that contain ingredients that cockroaches avoid.

Only microgram quantities of active ingredient in bait are needed to kill individual cockroaches (Hamilton and Schal, 1988; Reid et al 1990). Since cockroaches consume milligram amounts of food per day, the decline in activity of bait over time may be related to gradually declining palatability. It appears that most cockroach baits require multiple feeding bouts in order to provide kill. Reduced palatability may occur as a result of a change in the physical characteristics of the bait (eg. it may dry our or become moldy), or if surviving cockroaches find an alternative food source.

Foraging patterns

The sweeping, widespread foraging behavior of yellowjackets and ants makes them particularly vulnerable to control with bait. Because cockroaches apparently have more restricted foraging behavior, factors that increase foraging generally increase bait activity. Starvation, dehydration, or crowding increases cockroach movement and results in increased contact with bait. For bait to be successful, however, a high proportion of the population must feed on the bait.

The foraging and feeding pattern of adult female cockroaches with oothecae presents a difficult situation for the performance of bait. Nymphs and males feed nearly daily, but gravid female *B. germanica* do not. Females may remain sequestered for a few days without feeding at all. Although they eventually feed vigorously, offspring from sequestered females may represent a nucleus for reinfestation.

German cockroaches rarely travel extensive distance to food and water if those resources are provided close by. Individuals may emigrate from a mature or crowded population, but the bulk of the individuals will remain close to their aggregation as long as conditions are adequate. This makes it imperative that bait be placed where the cockroaches will easily locate it.

No significant insecticide resistance

Insecticide resistance may have a dramatic negative influence on the performance of bait for cockroach control. Insecticide resistance is rare among eusocial insects, so it is unlikely that significant resistance occurs in bait target pests such as termites, wasps and ants. We have observed significant levels of insecticide resistance among many field-collected populations of *B. germanica*, and resistance apparently allows survivorship when bait is presented. On the other hand, laboratory and field data indicate good possibilities for control with bait in instances where resistance has not become established.

Limited immigration

Bait efficacy improves if there is not a continual influx of pests from surrounding areas. The bait itself may remain biologically active, but *apparent* control is lessened if immigrants continue to come into the baited area. Seasonal control of eusocial insects can be achieved with bait as baited colonies are destroyed. Reinvasion may not occur until the following year. Because of the restricted distances cockroaches move, bait installed in specific sites for cockroach control normally needs only to affect a specific population, not numbers of cockroaches arriving from unbaited populations. This provides opportunities for bait to be used in specific places, such as near appliances and certain pieces of furniture, etc. without concern for reinvasion from distant unbaited areas. Our experience indicates that resurgence of cockroach populations in household and commercial buildings occurs from the maturation and development of existing remnant individuals of the population rather than from introductions or immigrants.

BIOTIC FACTORS THAT REDUCE THE SUCCESS OF BAIT

Learning, repellency and resistance

Cockroaches are excellent learners, and they can retain information for days (Hunter 1932; Ebeling et al 1966; Alloway 1972). Their learning depends on punishment, which in the case of bait may be the stimulus they get from a sublethal dose of bait they eat or contact. Chemicals they deposit may also assist cockroaches learn to avoid objects in their environment (Alloway 1972; Ross and Tignor 1986). It can be presumed that many insects are capable of associative learning.

Depending upon concentration, most chemicals are repellent to insects, and insects tend to avoid baits incorporating repellent insecticides and ingredients. Wasps and ants are particularly sensitive to low concentrations of insecticide added to their food, and will avoid it (Wagner and Reierson 1969; Knight and Rust 1988). To varying degrees, cockroaches will avoid a variety of insecticide deposits, repellency usually increasing with increasing concentration . Fast-acting insecticides are avoided more than slow-acting ones (Ebeling, Reierson and Wagner 1967). Bait acceptance can be reduced or in some instances totally eliminated by the addition of a toxic substance. As mentioned previously, an example of this was found with the southern fire ant, colonies of *S. xyloni* rejecting bait impregnated with a very low concentration of avermectin. Palatability screening trials eliminate most repellent insecticides from consideration as active ingredient, but few trials examine the repellency of inert ingredients.

Insecticide resistance has been documented in more than 500 species of insects. It is apparently widespread among *B. germanica*, resistance and cross-resistance occurring at different levels to many insecticides. Although the relevance of insecticide resistance in the control of *B. germanica* is undetermined, we have shown it to be particularly important for control with bait. We have attributed most control failures with bait to a combination of learning and insecticide resistance.

Survivorship attributable to low levels of insecticide resistance may be amplified through learning. Most baits we recover from field situations remain biologically active against susceptible cockroaches, even after several months. This suggests that field populations survive because of factors other than deterioration or degradation of bait and bait actives. Even in small arena tests, resistant field-collected cockroaches exposed to fresh bait survive for long periods of time, especially if competitive food is provided (Table 3). Resistant cockroaches surviving initial feeding bouts on baits may learn to avoid subsequent contact with the bait. Even our most resistant strains succumb if unadulterated competitive food is not provided. Single feedant baits may more effectively counteract resistance. Baits requiring multiple feeding bouts to provide kill may be more affected by insecticide resistance.

TABLE 3 - Effect of insecticide resistance on the mortality of *B. germanica* produced by toxic baits.

Strain	Resistance	% Alive at Day 14 Combat	% Alive at Day 14 Raid Max
Lab (OB)	None	0	0
LA-23/5	Moderate	40	42
LA-37/5	Moderate	--	37
LA-37/3	High	--	94

Alternate Food; 6-8 Reps of 10 *B. germanica*

CONCLUSIONS

Because of advantages inherent with bait, bait will continue to be an excellent component of most integrated urban pest management strategies. Designer baits are particularly appropriate for insects such as wasps and ants, and for seasonal migrants such as crickets, peridomestic cockroaches, and millipedes.

The efficacy of baits for control of *B. germanica* is related to biotic and abiotic factors. Bait success is improved with improved sanitation, proper bait placement, good bait acceptance and palatability, and a lack of significant insecticide resistance.

Bait efficacy is reduced when sanitation is poor and where there is excessive clutter (refugia). Efficacy is also reduced when repellent residual insecticides are used improperly in conjunction with the bait, and where too few baits are installed close to where the cockroaches reside. Gravid female cockroaches may provide a nucleus for rapid resurgence of baited populations.

Learning and insecticide resistance appear to combine to seriously deter the effectiveness of bait. Learning may amplify insecticide resistance. Resistant cockroaches succumb to toxic bait if unadulterated competitive food is not available, presumably because the cockroaches eat more bait than they can detoxify. If competitive food is available, however, bait efficacy drops precipitously as surviving cockroaches learn to avoid subsequent contact with otherwise lethal bait, and feed on the unadulterated food in preference to the bait.

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Recent Advances in Termite Biology and Control

Nan-Yao Su and Rudolf H. Scheffrahn
Ft. Lauderdale Research and Education Center,
University of Florida, Institute of Food and Agricultural Sciences,
Ft. Lauderdale, Florida 33314

Abstract. In 1990, the International Isoptera Society was established to facilitate interaction among all termitologists. Advances continue in the taxonomy of the North American termites and the population dynamics of subterranean termites. Due to environmental concerns, non-chemical alternatives have attracted increasing attentions in recent years. Reduced pesticide load techniques such as toxicant-bait and physical control or exclusion devices will probably become major components of future IPM programs for termite control.

International Isoptera Society

In September 1989, several termitologists attending the symposium, "Current Research on Wood-destroying Organisms and Future Prospective for Protecting Wood In Use", held in Bend, Oregon, discussed the possibility of forming a society for students of termitology. A survey letter was drafted and sent to over 270 prospective members. Excerpts of the letter read, "... we have recognized a need for increased interaction among termitologists... There is especially a need to facilitate communication within and between those interested in basic and applied termitology."

By the summer of 1990, 168 people from 31 countries responded in favor of forming such a society. Currently, the International Isoptera Society has over 230 members registered from 41 countries. Most of the Society's activity is reported in the bi-annual *Isoptera Newsletter* which includes items such as society news, papers presented in past meetings or scheduled for upcoming meetings, "in press" articles (titles of accepted papers which await publication), research and membership news, information on species or specimens sought, techniques, collection news, employment and grant opportunities, travel logs, announcement of publications, and membership updates. A unique forum called "Pellets" provides a place to "present and discuss ideas, hypotheses, questions, and issues relating to termitology, free of the constraints of editors' opinions or reviewers' objections..."

In 1991, the "List of Termitologists" was published as the Society's membership roster. The list includes those actively involved in all aspects of termite research and control. With this list, it is now possible to establish contact by mail, telephone, fax or E-mail with anyone interested in termitology. Recently, we also organized a Workshop on Termites to be held in conjunction of the XIX International Congress of Entomology in Beijing, China. This workshop includes over 50 papers from 17 countries.

Taxonomy

The first comprehensive treatise on the termites of the Nearctic region was compiled by Banks & Snyder (1920). Over the next three decades, numerous species descriptions and revisions by T.E. Snyder, S.F. Light, and others were included in Snyder's (1949) world catalog. Generic reassignments from Krishna's (1961) revision of the Kalotermitidae and the Nearctic establishment of *Coptotermes formosanus* Shiraki were recorded in Araujo's (1977) catalog. Fontes (1983), in an update of Araujo's work, included *Incisitermes fruticavus* from southern California (Rust 1979).

More recent additions to the Nearctic termite fauna include *Amitermes floridensis* from central Florida (Scheffrahn et al. 1989) and the karyotypically-distinct *Neotermes luykxi* from southeastern Florida (Nickle & Collins 1989). Haverty et al. (1989a) have proposed a new subspecies of *Zootermopsis nevadensis, Z. n. nuttingi*, based on the cuticular hydrocarbon complement and agonistic behavior among populations of this northwestern U.S. species. Acceptance of a new southeastern species of *Reticulitermes, R. malletei*, (Clement et al., 1986) should be deferred until data can support a valid species ranking for the designated population. In recent years, extensive collecting in the western U.S. indicates that additional species of *Reticulitermes* warrant description based on morphometric data (T. Myles, pers. comm.).

At present, 44 species are recognized from the 50 states. As termite collecting in the United States continues, exotic species are introduced and become established, a clear and workable species definition for Isoptera emerges, and additional characters are recognized, it is expected that taxonomic status of termites will continue to evolve.

Population Demography

Despite being one of the most economically important structural pest genera in the United States, little is known about the foraging behavior and population dynamics of the subterranean termites, *Reticulitermes* spp. The success and reliance on the termiticide barrier method for last four decades probably contributed to the lack of interest in the study of how these termites exploit food resources.

A mark-recapture study by Esenther (1980) estimated ca. 1-3 million foraging termites for *Reticulitermes flavipes* (Kollar). This Lincoln index estimate was ca. 10-fold larger than the direct count of *R. flavipes* as reported by Howard et al. (1982). According to Grace et al. (1989) who used Sudan Red 7B as a marker, *R. flavipes* in metropolitan Toronto forages up to 75 m and contains 2-3 million termites per colony.

Sudan Red 7B caused unacceptably high mortality of *R. flavipes* at high concentrations and was visibly retained less than two weeks when sub-lethal doses were used (Su et al. 1988). Because of the large standard errors inherent in the estimates derived from a simple Lincoln index, a weighted mean model with a multiple capture-recapture procedure (Begon 1979) was adopted to improve the accuracy of the estimates of foraging populations of the Formosan subterranean termite, *C. formosanus* (Su & Scheffrahn 1988a). The procedure requires a marker that exhibits minimum lethal effects against termites yet visibly resides in termites long enough (ideally 4-8 weeks) to complete several (> 3) capture-recapture cycles. A dye, Nile Blue A, was identified to possess these characteristics for both *R. flavipes* and *C. formosanus* from a laboratory screening study (Su et al. 1991a). Subsequent field studies using Nile Blue A indicated foraging populations of *R. flavipes* may contain 0.1-5 million termites per colony (Su et al., unpublished data).

Control

A. Soil termiticides

The soil barrier method remains the major component of subterranean termite control. After the withdrawal of cyclodienes in 1987, several types and formulations of organophosphates and pyrethroids have been marketed as termiticides for the pest control industry. Although less persistent in soil (Mauldin et al. 1987), a laboratory study showed the new termiticides are generally 10-100 times more effective in preventing termite tunneling through soil than chlordane (Su & Scheffrahn 1989a). Recent studies with soil termiticides have focused on their distribution in soil when different formulations and application technologies are used (Mampe & Bret 1992, Su et al. unpublished data).

B. Non-traditional approaches

a) Detection and monitoring. Various methods for detecting active infestations of termites in structures have been available to the pest control industry. These include electronic stethoscopes, termite-detecting dogs, moisture monitors, and, more recently, a device that detects methane, a termite waste product. None of these commercially available techniques, however, have been thoroughly tested for their efficacy. A research project has been recently initiated to examine the feasibility of assessing termite activity with acoustic emission detectors (Lewis & Lemaster 1991).

Monitoring the populations of cryptic subterranean termites is an essential step toward a successful program of integrated pest management (IPM). Field traps comprising toilet rolls (La Fage et al. 1973), wooden blocks (Tamashiro et al. 1973, Su & Scheffrahn 1986), and corrugated cardboard (Grace et al. 1989) have been used for studying foraging populations and territories of subterranean termites. A simpler method, however, has to be developed for the pest control industry to better survey subterranean termite populations with control as the primary objective.

b) Remedial control devices. Due to the increasing public awareness of environmental issues, non-chemical alternatives have become more popular in recent years. Because such methods can only be administered above ground within a structure, they are primarily used to control drywood termite infestations. Control by electrocution using a device called the Electrogun[R] (Ebeling 1983), heat treatment of whole structures (Forbes & Ebeling 1987), exposing infested wood to liquid nitrogen to freeze kill a localized infestation (Forbes & Ebeling 1986), and the use of a microwave emitting device to control inaccessible infestations (V. R. Lewis, pers. comm.) have been used commercially. Except for the preliminary studies referenced above, none of these non-chemical control measures have been thoroughly evaluated. Recently, a research project was initiated (V. R. Lewis, pers. comm.) to properly evaluate these non-chemical techniques for remedial control of drywood termites.

c) Physical exclusion devices. Current soil termiticide barrier treatments are essentially exclusion devices. There is no evidence to show that subterranean termite populations are significantly reduced after soil treatments. Non-chemical barriers can also achieve similar results. Ebeling & Pence (1957) first suggested an alternative control when they discovered that layers of sand particles ranging in size from 10-16 mesh (equivalent to particles of 1.2-1.7 mm in diameter) were not penetrated by the western subterranean termite, *Reticulitermes hesperus* Banks, in a laboratory test. Their observation indicated that the particles were too large for termites to displace with their mandibles, yet were small enough so termites could not maneuver between them. Later, Tamashiro et al. (1987) confirmed that the finding of Ebeling & Pence (1957) could be applied to *C. formosanus*. Their results showed that the Formosan subterranean termite did not penetrate sand layers composed of particles 1.7-2.4 mm in diameter. Our laboratory (Su et al. 1991c) results showed that *C. formosanus* penetrated the least through particles of 1.70-2.36 mm in size, while a wider size range (1.00-2.36 mm) excluded penetration by the eastern subterranean termite, *R. flavipes*. When several sizes were uniformly mixed, the resultant barriers composed of particles in the 1.18-2.80 mm range effectively shielded penetration by both termite species.

Results of a field study demonstrated that field populations of subterranean termites are more successful in penetration of sized particle barriers than laboratory groups (Su & Scheffrahn 1992). This was especially true for *C. formosanus* populations that generally have larger numbers and wider ranges of foragers' body sizes (2.5-6 mg per termite) than those of *Reticulitermes* spp. (1.5-2 mg per termite). Although both laboratory and field studies demonstrated the potential of a sized particle barrier as an exclusion device for subterranean termites, further studies are needed to determine the proper installation procedure under various construction scenarios.

Another physical exclusion device recently developed is a stainless-steel mesh which is installed between structure and soil. This pre-construction procedure is currently available only in Australia (Verkerk 1990).

C. Biological control

The above-ambient humidity and temperature in nests of subterranean termites are suggestive of favorable microbial growth. Fujii (1975) demonstrated the pathogenicity of an entomogenous nematode (*Neoaplectana carpocapsae* Weiser) against *C. formosanus* under laboratory conditions. However, he also reported the difficulty of nematodes to enter natural openings of termites due to the nematodes' relatively slow mobility. Although nematodes have been commercially marketed (trade named Spear^R) for subterranean termite control, Mauldin & Beal (1989) reported the failure of such products to affect foraging activity of field populations of *Reticulitermes* spp. Lai et al. (1982) determined the pathogenicity of the entomogenous fungi, *Metarhizium anisopliae* Sorokin and *Beauveria bassiana* (Balsamo) Vullemin against *C. formosanus* under laboratory conditions. Field trials failed when infected *C. formosanus* workers were shunned by their healthy nestmates. *Beauveria bassiana* did not complete its development due to insufficient illumination in the termite galleries (Lai 1977). Field results reported by Hänel (1983), who successfully triggered an epizootic of *M. anisopliae* in colonies of an Australian mound-building termite, *Nasutitermes exitiosus* (Hill), demonstrated the potential for termite control if the proper combination of pathogen and delivery system are used.

D. Bait-toxicant

Foraging galleries of subterranean termites may include many nesting structures (main nest and satellite nests) or underground foraging sites (logs, fill debris, roots, etc.) interconnected by tunnels. Gallery systems extend for up to 100 m for *C. formosanus* (Su & Scheffrahn 1988a) and up to 79 m for *R. flavipes* (Grace et al. 1989). Damage to structures is initiated when termite activity extends from peripheral foraging sites below ground to the structure itself (Fig. 1A). Despite the large quantities of pesticides used, soil treatments do not appear to affect termite populations but only provide barriers to separate structures from soil-borne termites (Fig. 1B). Colonies of subterranean termites remain viable near the structures even after treatment (Su & Scheffrahn 1988a). Because of the apparent inability of current control techniques to reduce existing subterranean termite populations, the severity of infestations by *C. formosanus* in areas such as Honolulu, Hawaii, New Orleans, Louisiana, and Hallandale, Florida, has increased in recent years.

Researchers early in this century first observed that slow-acting arsenic dusts could be used to control termites by exploiting their own social behaviors (Randall & Doody 1934). The principle of suppressing colony populations is to provide a means for individual termites to acquire a lethal dose of slow-acting toxicant at an accessible foraging site. The intoxicated individuals must not be so impaired at the onset of exposure that they cannot move away from the toxicant acquisition site and continue contact with nestmates. The slow-acting characteristic of a toxicant is particularly important because accumulation of a large number of dead termites at the acquisition site will repel other nestmates from approaching the toxicant (Su et al. 1982). Ideally, the toxicant has to be nonrepellent to termites, or at least be masked by other agents to prevent feeding deterrence or avoidance behavior by foragers. Under this premise, the toxicant can be incorporated into a bait (feeding acquisition) or tracking powder (contact and grooming acquisition).

The two important characteristics of a bait-toxicant, slow-acting and no feeding deterrence, are concentration dependent (Su et al. 1987). A desirable toxicant should be accepted by termites at efficacious concentrations to cause significant delayed mortality. An index combining these three parameters, concentration, delayed mortality, and feeding deterrence (Bait Toxicant Efficacy, or BTE index), therefore, can be used to evaluate the potential of a toxicant (Su & Scheffrahn 1991). BTE was defined as the quotient of bait acceptance threshold concentration (BATC) and the threshold concentration to produce significant delayed mortality (DMTC); namely BTE = BATC/DMTC. A toxicant with BTE < 1 (such as pyrethroid, Su et al.

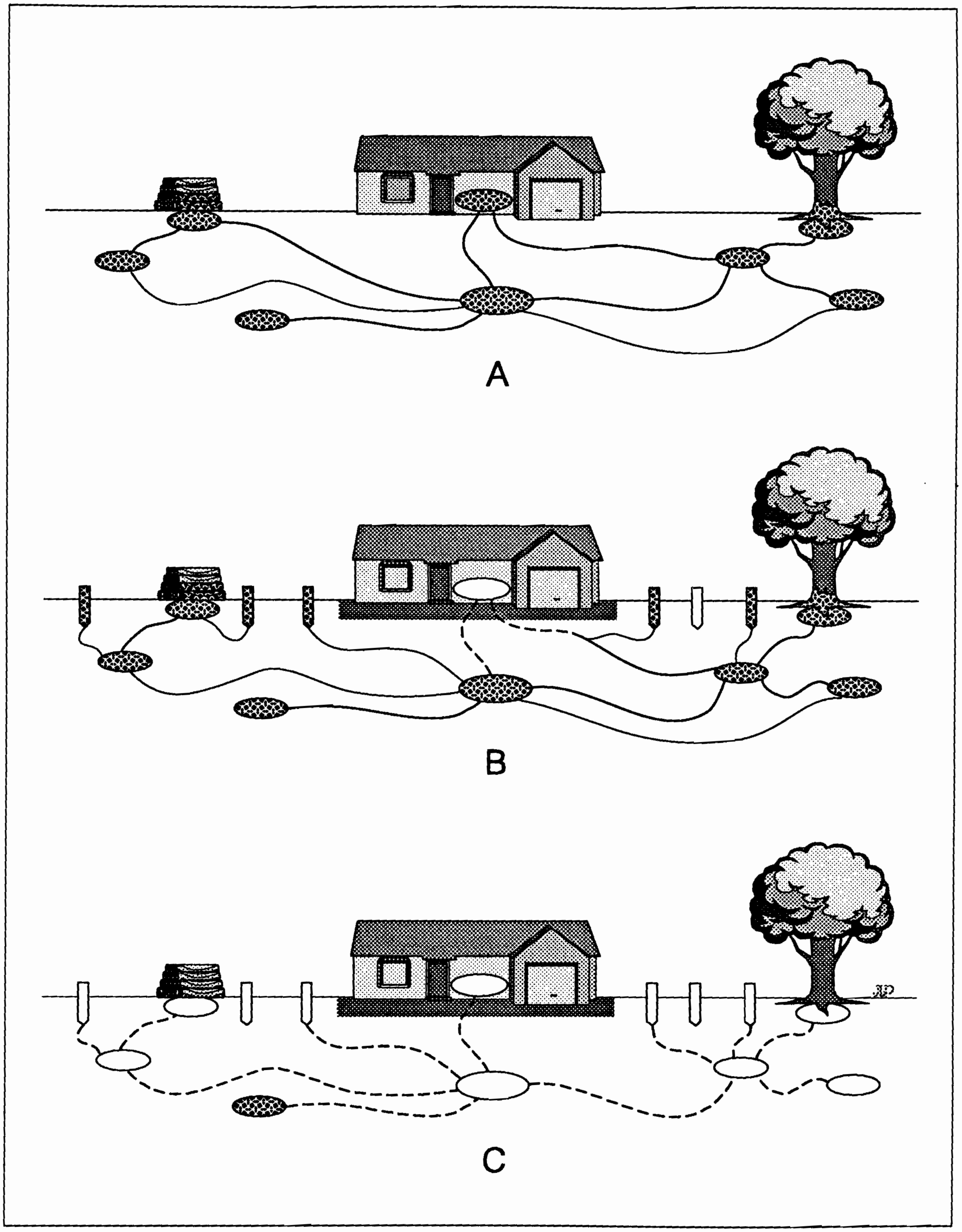

Fig. 1. Subterranean termites construct elaborated gallery systems in the soil and invade houses when the foraging activity moves above the soil surface (A). The conventional soil treatment (shaded area) provides barriers to separate structures from soil-borne termites (B), but termite populations remain active near the structure. Using a baiting program, subterranean populations and foraging zones may be reduced to the extent that damage potential to structures, and other wood materials on the soil surface, is minimized (C).

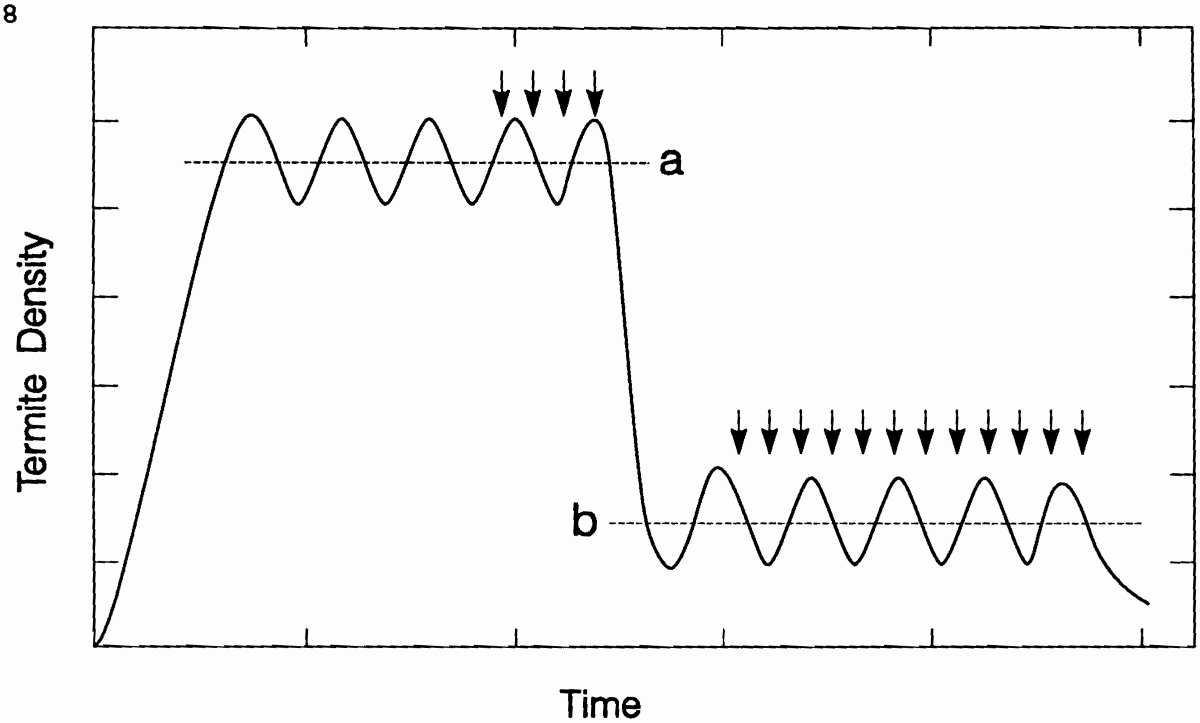

Fig. 2. Subterranean termites become pests when their populations attain a damaging level (a). A baiting program may be used to suppress their populations to levels (b) which no longer pose a threat to structures.

1982) cannot be used in a bait, while BTE > 1 indicates a compound with a good bait-toxicant potential.

Beard (1974) suggested the use of bait toxicants as a possible strategy to eliminate established colonies of the subterranean termites, *Reticulitermes* spp. Dechlorane (mirex) baits were used to suppress activity of field colonies of *Reticulitermes* in the United States (Esenther & Beal 1974, 1978), and to kill field colonies of an Australian subterranean termite, *Mastotermes darwiniensis* Frogg. (Paton & Miller 1980). Gao et al. (1985) also reported successful field control of termite infestations with mirex baits in China.

Laboratory studies indicated that hydramethylnon (Amdro^R), avermectin B_1 (Su et al. 1987), A-9248 (diiodomethyl para-tolyl sulfone) (Su & Scheffrahn 1988b), sulfluramid (Su & Scheffrahn 1988c), and insect growth regulators (IGRs) such as methoprene, fenoxycarb, and S-31183, have shown delayed toxicity against *C. formosanus* and *R. flavipes* (Jones 1984, Su et al. 1985, Haverty et al. 1989b, Su & Scheffrahn 1989b).

In a preliminary field trial with fenoxycarb baits, Jones (1988) observed an increase of presoldiers and soldiers in colonies of *Reticulitermes* species and a subsequent decline in their foraging activities. Our field study with baits treated with a slow-acting toxicant (A-9248) demonstrated that foraging populations of three *C. formosanus* colonies were reduced 65-98% (Su et al. 1991b). These results demonstrate that a toxicant bait can be used to suppress foraging populations of subterranean termite colonies and hence reduce their damage potential.

Subterranean termites become pests when their populations attain a damaging level (Fig. 1A, Fig. 2a). A baiting program may be used to suppress their populations to levels (Fig. 2b) which are no longer threatening to structures (Fig. 1C). Because baits are point-sources of toxicant, a baiting program requires much less total amount of pesticide than current broad-application soil termiticide treatments. Population-suppressing techniques and physical barriers will probably become major components of future IPM programs for termite control.

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CHEMICAL COMMUNICATION IN COCKROACHES

Coby Schal

Department of Entomology
Rutgers University
Cook College
New Brunswick, New Jersey 08903

ABSTRACT - Although the pheromones of several hundred insect species have been identified and many are in current use in IPM, the sex pheromones of only two cockroach species have been elucidated. This chapter briefly reviews the occurrence of sex pheromones, aggregation and dispersion-inducing pheromones, and allomones in cockroaches, their sites of production, regulation, and use in IPM. The primary objectives of this discussion are to highlight how little is known about cockroach semiochemicals and to encourage more concerted efforts in research and extension to identify and employ these compounds in urban IPM.

Keywords - cockroach, pheromones, allomones, monitoring, IPM

INTRODUCTION

Cockroaches offer excellent material in which to study chemical communication. The nocturnal habits of most of the 4000 species of cockroaches predispose them to communicate with chemicals. Their close phylogenetic relationship to termites, and their tendency to aggregate, suggest that certain similarities might be found to the complex social chemical communication found in termites. The close relationship of cockroaches to orthopterans suggests that, like metanotal secretions in the latter, chemical gift-giving might also be found in male cockroaches, and calling by female cockroaches might be common. Also, the leaf-litter habitat of many outdoor species suggests that intricate chemical mechanisms have evolved to deal with invertebrate predators, such as ants and spiders.

Indeed, cockroaches produce and secrete chemical mediators that function in defense against predators and parasites, in promoting aggregation, in agonistic interactions and resource partitioning (epidiectic interactions), and in species, sex, and kin recognition. My objectives in this short paper are to briefly review the use of chemicals in communication by cockroaches and to identify specific areas that need further investigation.

ALLOMONAL SECRETIONS

Defensive secretions of cockroaches have been studied more extensively than pheromones, possibly because of their potential as arthropod repellents. These chemicals are usually not responsible for the typical odor of different species; other compounds are involved. Two types of chemical defenses have been described in cockroaches: (a.) Active chemical defenses are liquid secretions that act as contact irritants (e.g., aldehydes, quinones), they are discharged in response to predators, usually from eversible glands that ooze or spray, and are effective against vertebrates as well as invertebrates, and (b.) Passive chemical defenses which involve viscous, glue-like secretions (mainly protein and glycoproteins) that accumulate on the cuticular surface and are effective against small invertebrates (see Schal et al. 1982). The latter are found mainly in the families Blattidae (e.g., *Blatta orientalis)* and Blattellidae (e.g., *Nyctibora* spp.), while active defense occurs in most families. Allomonal secretions in cockroaches are extensively reviewed in Roth & Alsop (1978) and Brossut (1983).

Cockroaches that produce active chemical defenses usually also exhibit aposematic coloration. They produce mainly aliphatic compounds in two phases, a volatile organic phase and a nonvolatile aqueous carrier. Brossut (1983) described 43 volatile products, with *trans*-2-hexenal being a major component in many species. This, and related compounds, cause vertigo and nausea in vertebrates and repel ants, birds, lizards, and frogs. Other constituents include 2-methylene butanal, 2-methylene pentanal, 2-methylene propanal, isovaleric acid, isobutyric acid, 2-pentanol, 2-heptanol, octenal, various phenols, which may have bactericidal properties as well, and benzoquinones. The nonvolatile fraction usually contains glucose derivatives, such as gluconic acid, and its function remains unknown.

Allomonal secretions have tremendous potential as repellents, as do other natural products, including botanicals, that can manipulate the distribution of cockroach populations to effect better pest control. This potential has yet to be realized in the commercial sector.

AGGREGATION PHEROMONES

All cockroaches studied to date exhibit a tendency to aggregate. Among the possible reasons for aggregating are:

- enhanced resource-based mate finding,
- microclimate, particularly humidity, control,
- food and symbiont exchange, as in termites, and
- improved growth and reproduction.

Indeed, in all cockroaches, grouped nymphs develop faster than isolated individuals (Willis et al. 1958), and we recently showed that German cockroach adult females reproduce faster in groups than in isolation (Gadot et al. 1989).

Ishii & Kuwahara (1967) showed that in the German cockroach, *Blattella germanica* (L.), nymphs choose resting places that had been impregnated with cockroach odors, and that this tendency was inter-specific (see also Bell et al. 1972, Roth & Cohen 1973). Ishii & Kuwahara (1967) also localized the active aggregation-inducing compounds in the posterior portion of the abdomen in association with the rectal pads. Subsequent attempts at isolating the aggregation pheromone have largely failed or resulted in ambiguous behavioral data. Fuchs et al. (1985) isolated from feces 150 compounds, including 57 carboxylic acids, and suggested that the aggregation pheromone might be some mixture of these acids. McFarlane & Alli (1986) found that lactic acid in filter paper contaminated by cockroaches attracted and arrested nymphs.

The use of the term "aggregation pheromone" is confounded by its source; usually excreted material is assayed and this material could well serve as a food attractant or waste product, hence the inter-specific activity. For example, fatty acids in feces are clearly attractive, but may not serve as the aggregation pheromone. Thus, terms such as "fecal extract" or "mandibular extract" should be used until a pheromone is isolated. Also, assays for aggregation pheromones must consider the intrinsic attractive nature of candidate compounds (i.e., anemotactic response) in addition to the arrestment response they elicit. Importantly, non-pheromone mediated social interaction among nymphs must also be considered in such assays.

Recently, Sakuma & Fukami (1990) argued for more appropriate assays of fecal extracts and adapted a Y-olfactometer to monitor the chemotactic and anemotactic responses of nymphs to volatile components extracted from frass-contaminated filter paper. Each methanolic extract of nymph-contaminated filter paper was cleaned with n-hexane and subjected to HPLC and GC analyses to separate primary, secondary and tertiary amines. They found that a small tertiary amine peak, 1-dimethylamino-2-methyl-2-propanol ($C_6H_{15}O_1N_1$) contained most of the chemotactic and anemotactic activity. Interestingly, this compound attracts nymphs in a Y-tube but not in the classical vertical filter paper assay employed by Ishii & Kuwahara (1967), suggesting that a separate arrestant is required to induce the aggregation.

Unlike *B. germanica*, in some cockroaches (e.g., *Blaberus craniifer*, *Eublaberus distanti*) mandibular glands are the primary source of aggregation pheromones, and ablation of these glands in males and females eliminates orientation of immature and adult males and females in a Y-olfactometer (Brossut 1979). The aggregation pheromones are comprised of volatile alkanes (including undecane and tetradecane), 2,6-dimethyl-2-heptanone, 4-heptanone, and octanol. Because these materials attract more adults than nymphs, they may also function as sex pheromones or general food attractants.

Brossut et al. (1991) also describe a tergal gland in *Cryptocercus punctulatus*, with linalyl acetate being the most abundant of 21 compounds and 4,6,8-trimethyl-7,9-undecadien-5-ol being specific to tergal secretions of females. The role of this secretion is unknown, but it may function in the complex familial organization of this cockroach.

DISPERSION-INDUCING AGENTS

Suto & Kumada (1981) showed that filter papers contaminated at high cockroach densities did not elicit aggregation responses in *B. germanica* (Fig. 1). Thus, aggregation pheromone is released at low densities, while at higher densities either less aggregation pheromone and/or dispersion agents are released. Because aggregation activity remained at both high and low density in association with feces, they concluded that aggregation pheromones continued to be secreted at all densities. At high densities however, dispersion agents were secreted as well in association with the saliva. It is not clear why such conflicting messages would be released by cockroaches simultaneously.

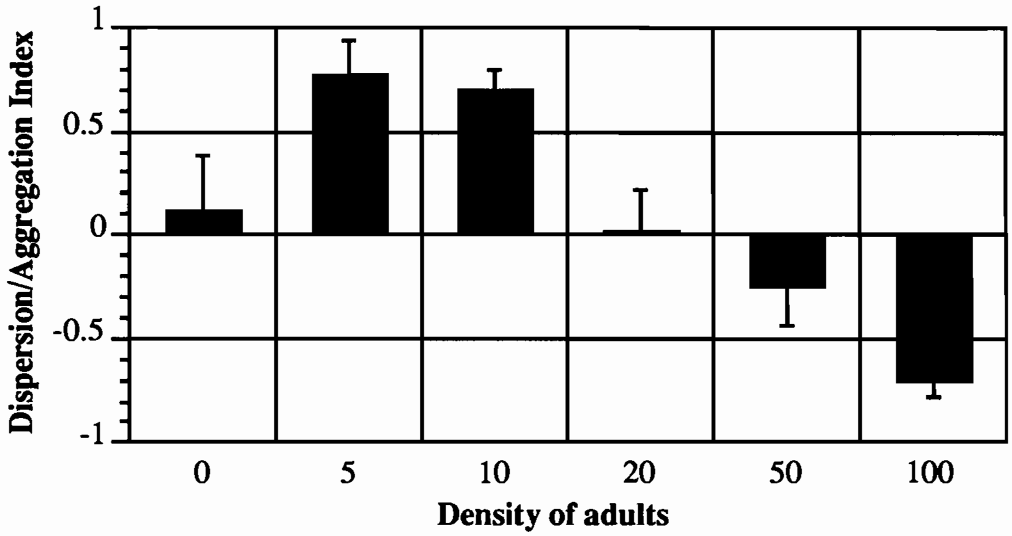

Fig. 1. Effects of adult density on the aggregation response of nymphs of *B. germanica* to contaminated filter papers. Figure adapted from Table 1 in Suto & Kumada (1981).

Nakayama et al. (1985) placed groups of 100 insects in 200 ml beakers to stimulate salivary secretion onto filter paper. They found interspecific repellent activity among *B. germanica* and several *Periplaneta* species, and that all stages of the German cockroach showed repellent activity. In contrast, Ross & Tignor (1986) found that adult males are repelled by paper conditioned by adult females but not by papers conditioned by nymphs or adult males; their assays measured responses to both aggregation and dispersant materials combined. Nakayama et al. (1985) showed that the dispersion-inducing materials were water soluble and heat stable and isolated two protein fractions of MW 5,000 and 70,000-100,000.

McFarlane (1984) also showed that propionic, isovaleric, and valeric acids, which are found in feces, are repellent to *B. germanica.*

It is not clear what role dispersion agents play in the regulation of cockroach distributions. The secretions of these materials are induced under artificial over-crowded conditions and it remains to be established whether these secretions are employed in natural populations. Furthermore, the recent finding (above) that the aggregation pheromone is water-, as well as methanol-soluble, again confounds the pre-1990 assays of crude methanolic extracts, which would contain both aggregation and dispersion agents.

SEX PHEROMONES

Males

Male volatile pheromones that function as primary attractants of females are relatively rare among cockroaches. Sreng (1990) identified seducin, the sternal gland secretion of *Nauphoeta cinerea,* as three volatile components in the ratio 4:4:1 3-hydroxy-2-butanone (acetoin), 2-methylthiazolidine, and 4-ethyl-2-methyoxyphenol. This secretion may also function in sexual selection and mate choice by the female.

The courting behavior of most cockroaches involves wing-raising by the male, which exposes the abdominal tergites, and mounting of the male by the receptive female. Two phases are involved in the female's response to the male's tergites: (a.) attraction, and (b.) arrestment and feeding. At least two major chemical fractions appear to be involved: A volatile fraction that attracts the female, and a non-volatile, possibly phagostimulatory, fraction that places the female in the proper position for copulation. Thus, male pheromones are involved in close-range communication between the sexes.

Tergal secretions are most common in Blattaria, Orthoptera, and Isoptera. Tergites may have distinctive cuticular modifications, or concentrations of cuticular pores in association with glandular cells, as described by Brossut & Roth (1977). In *B. germanica*, the tergal gland is found on tergites 7 and 8. It is made up of 2 depressions (250 µm long x 60 µm wide) in the cuticle divided by a central ridge; they serve as reservoirs for the secretions. Between the depressions are numerous chemo- and mechano-receptors. Modified epidermal cells produce products which are secreted through cuticular ducts formed by duct cells.

Brossut et al. (1975) concluded that in *B. germanica,* the male tergal secretion consists of a nonvolatile protein fraction of 8 electrophoretic bands, including 2 glycoproteins, and a volatile fraction that includes para-hydroxy benzylic alcohol, *O*-hydroxy benzylic alcohol, di- and tri-methyl naphthalene, benzothiazole, 2 isomers of nonyl phenol, and the free fatty acids myristic, palmitic, and oleic acids. Interestingly, they also reported large amounts of saturated C24 to C29 alkanes (even and odd chain lengths at equal amounts), presumably from the cuticular surface. This is in contrast to our recent identifications of mainly C27 and C29 methylalkanes from the cuticular surface of the male German cockroach (Jurenka et al. 1989). The behavioral activity of the volatile products remains to be established. Clearly, some, including the fatty acids, appear to be non-specific food attractants (Wileyto & Boush 1983), and have been isolated as well from frass as candidate aggregation pheromones (Fuchs et al. 1985).

From *P. americana* male tergal glands, Brossut et al. (1975) isolated 3 proteins as well as 2-pentanone, 3-pentanone, 3-octanone, and 2-, 3-, and 4-methylcyclohexanone. It is interesting that some of these compounds are used as allomones by other insects and they clearly repel ants.

Females

In the last three decades, the female sex pheromones of several hundred species of insects have been isolated and identified (Tamaki 1985). The majority of these compounds are from agriculturally important lepidopteran and coleopteran pests, while the sex pheromones of only two species of cockroaches have been identified. A recent review of the female sex pheromones of cockroaches can be found in Schal & Smith (1990).

Roth & Willis (1952) described in great detail the involvement of a female-produced sex attractant in the sexual behavior of the American cockroach, *P. americana,* several years before the word "pheromone" was coined in 1959. Persoons et al. (1976) identified two sesquiterpenoid pheromone components, periplanone-A and periplanone-B, and periplanone-B was confirmed by total synthesis (Still 1979). The site of production of these pheromones remains unknown, although extracts of midguts and frass from females are known to elicit behavioral responses in males.

Supella longipalpa: As in many Lepidoptera, the female brown-banded cockroach, *S. longipalpa*, produces a volatile pheromone which she releases during calling bouts (Smith

& Schal 1990). She elevates her wings, lowers the abdomen and expands her genitalia during pheromone emission which occurs predictably during the scotophase (Smith & Schal 1991). The male responds to this pheromone from a long distance with either directed running or flight (Liang & Schal 1990). Unlike most lepidopterans, where the sex pheromone gland can be easily localized in association with the ovipositor, in the brown-banded cockroach the calling behavior suggested that the tergum, genital atrium, or digestive tract might be involved. We used a two-choice olfactometer to monitor pheromone production. Behavioral assays of males with hexane extracts of various female body parts showed that the tergum was most active and that the abdomen was significantly more attractive than any other region of the body, including the alimentary canal (Schal et al., submitted). A direct comparison of successive tergites showed that the concentration of pheromone was greatest in tergites 4-5, and electroantennograms (EAG) clearly supported the behavioral results. A morphological SEM survey revealed distinct pores on the cuticular surface, and the density of pores corresponded to the amount of pheromone that was extracted. TEM studies confirmed the presence of modified secretory epidermal cells in association with these pores. These behavioral, electrophysiological, and morphological results strongly support the notion that the sex pheromone of the brown-banded cockroach is produced by the middle tergites, mainly in tergites 4 and 5.

Using the Y-tube olfactometers, we also showed that females initiated the production of sex pheromone 4 days after the adult molt, and calling behavior is not exhibited until the next day, on day 5 (Smith & Schal 1990). These results suggested that physiological changes during the first 4-5 days were involved in the synthesis of sex pheromones and in the expression of calling behavior. Our results from monitoring the activity of the corpora allata (CA) *in vitro* showed that juvenile hormone (JH) synthesis increased in the first few days after the imaginal molt in a pattern that corresponded to the pattern of pheromone synthesis and calling (Smith et al. 1989). That JH was involved in the regulation of both the production of the sex pheromone and in its release during calling behavior was clearly substantiated with the appropriate surgical procedures: Ablation of the CA eliminated both pheromone production and calling behavior, and JH replacement with either active CA or with the JH analog hydroprene restored both pheromone production and calling (Smith & Schal 1990).

Armed with information on the temporal pattern of pheromone production and release, its inducibility with JH, and the precise site of pheromone production, we have undertaken to elucidate the structure of the sex pheromone. In collaboration with Drs. Wendell Roelofs and Ralph Charlton (Cornell University, Geneva, NY), we have extracted the tergites of some 12,000 virgin females, obtaining about 6 μg of pheromone. This material was then separated on silica gel to remove mainly the cuticular hydrocarbons, the active fraction was then injected into a preparative non-polar GLC column, the fractions were collected and tested by EAG and behavior, and active fractions were then re-injected into an analytical polar capillary column. Fractions from the capillary column were again collected and tested by EAG and behavior, and a single active fraction was found to contain all the activity. This fraction, containing one active compound, was then subjected to high resolution mass spectrometric analysis, infra-red and UV spectral analysis, NMR, and microchemical reactions. We expect to have a complete structure and synthesis of the pheromone in the next few months.

Blattella germanica: Nishida & Fukami (1983) summarized work on the isolation, identification, and behavioral activity of components of the contact sex pheromone of the German cockroach. A behavioral assay developed by Roth & Willis (1952) proved to be very effective in evaluations of fractions of female extracts and of analogs of the pheromone components. Three components were isolated and identified from a hexane extract of several thousand females: All three possess a 3,11-dimethyl-2-nonacosanone skeleton with either a methyl, alcohol, or aldehyde functionality at the C29 position.

As in many lepidopteran pheromones, specific stereoisomers are produced by the female; all components possess 3S,11S configurations. However, unlike lepidopterans, all combinations of stereochemical isomers of the 3,11-positions yield similar wing-raising activity in males, indicating that the male receptor may not possess stereospecificity. Nishida and co-workers also showed that

- each of the 3 components elicits behavioral responses independently,
- biological activity is proportional to the polarity of the moiety at C29 and at C2; thus the female's pheromone could be improved by increasing its polarity,
- 3,11- side chains are essential for biological activity, and
- alkyl chain length is important.

The cuticular hydrocarbons of the German cockroach are mainly mono- and dimethyl alkanes 27 and 29 carbons long (Jurenka et al. 1989). In females, 3,11-dimethylnonacosane is the most abundant hydrocarbon and it is an isomeric mixture of 3,7-3,9- and 3,11-alkanes. This suggested to us that the hydrocarbon may be oxidized in a sex-specific manner to yield the methyl ketone sex pheromone (Chase et al. 1990). Because this reaction may be specific to a 3,11-branching pattern, and the C27 dimethyl alkane is present on the cuticle, it also suggested that the C27 methyl ketone may also serve as a sex pheromone. Recently, we identified the C27 methyl ketone as a pheromone component and established that it has biological activity, but it is about an order of magnitude less active than the C29 methyl ketone (Schal et al. 1990). Thus, a new pheromone component was discovered based on inferences from the biochemical pathways, as has been done with several lepidopteran pheromones.

As in *Supella*, in *B. germanica* too, JH is involved in the production of the contact pheromone (Schal et al. 1991).

COCKROACH SEMIOCHEMICALS IN IPM

As in agriculture, pheromones have tremendous potential in the detection, monitoring, and control of cockroaches. Sampling and monitoring indoor cockroach populations is both a long-term component of IPM and a first step of a well planned inspection. Because the cockroach population is distributed unevenly in a highly heterogeneous environment, the urban inspector evaluates the causes and sources of infestations mainly through intensive sampling of smaller areas (see Schal & Hamilton 1990). This is in contrast to the agricultural scout, who usually estimates pest populations through extensive sampling. To achieve effective intensive sampling, reliable and efficient traps are required. However, the traps ("glue boards") that are currently in use are inefficient because they have a very limited capture space and they do not sample cockroaches that retreat to deep, insecticide-free harborages. Traps with better attractants that can extend the reactive distance of cockroaches are clearly needed. Indeed, "lack of efficient trapping methods for cockroaches is probably the most significant single factor contributing to a heavy reliance on scheduled applications of insecticides" (Schal & Hamilton 1990).

Pheromones can also be used to enhance the efficacy of insecticides and biological control agents. Rust & Reierson (1977) convincingly showed that methanol extracts of *B. germanica* feces, presumably containing aggregation pheromone, increased the efficacy of three insecticides in field trials (Fig. 2). Similarly, Bell et al. (1984) showed that more *P. americana* cockroaches were killed in the field with insecticide sprays containing periplanone-B. Pheromones can play major roles in other approaches in cockroach control, including the dissemination of cockroach venereal diseases and biological agents, sterilization stations, and insecticide stations. In concert with repellent applications to certain areas, pheromones can be used to draw insects away from sensitive structures, as in hospitals (see Steltenkamp et al. 1992).

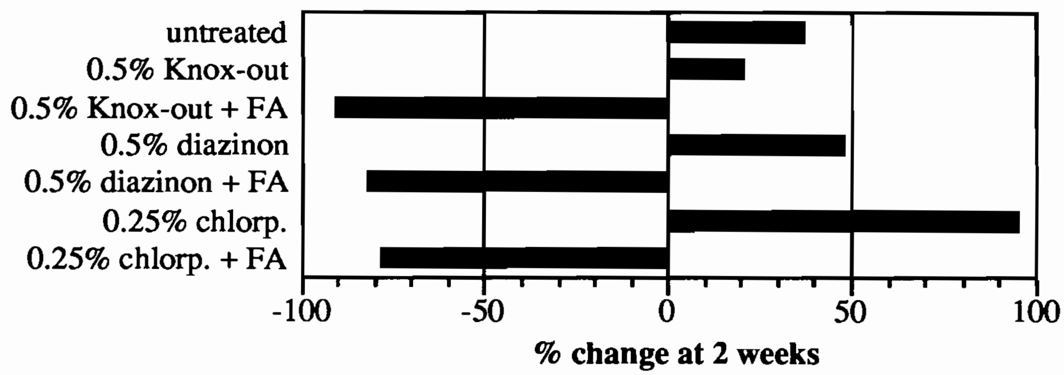

Fig. 2. Effects of *B. germanica* feces extract (FA) on the efficacy of the insecticides Knox-out, diazinon, and chlorpyrifos (chlorp.) in field trials. Adapted from Table 2 in Rust & Reierson (1977).

Despite the fact that almost 100 semiochemicals have been identified in cockroaches from 14 different glands, practical use of pheromones has been hampered by

- difficulties in identification,
- a lack of concerted efforts in research and implementation in IPM programs, and
- the fact that most identified compounds are from tropical species.

We hope that our current work will contribute to changing this perspective in the near future.

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COMMUNICABLE DISEASES AND VECTOR CONTROL - AN UPDATE

Jimmy K. Olson

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

ABSTRACT - There are a number of vector-borne diseases that continue to have serious impact on the health, economy and survival of the world's human populations. Malaria remains to be the most important in this regard. In the United States, the mosquito-borne, virus-caused encephalitides (e.g., St. Louis encephalitis) rank among the most important vector-borne diseases affecting human health at the current time. Both malaria and dengue pose a threat of returning and becoming once again endemic in the United States. Incidences of both diseases being locally transmitted by indigenous mosquito populations in the U.S. have been reported on several occasions in recent years. The vector potential for the dengue virus has increased and extended to the more temperate zone of the United States with the introduction and spread of the "Asian tiger mosquito," *Aedes albopictus* (Skuse). Lyme disease, caused by the spirochete, *Borrelia burgdorferi*, and vectored primarily by ticks of the genus, *Ixodes*, is a newly-detected vector-borne disease in the United States. The extent of this disease's occurrence, nature of its impact on human health, and methods by which it can be controlled are currently being investigated. Prevention and control of these and other vector-borne diseases are contingent on the establishment and maintenance of effective organized vector and vector-borne disease management programs. Support for such programs has waned in the United States in recent years in favor of dealing with other problems of human health deemed by the public to be of greater importance. Public and political support for vector and vector-borne disease control needs to be re-established if our nation's ability to protect its citizens from the ravages of such pestilences is to be preserved and sustained.

KEYWORDS - Vectors, vector-borne disease, vector control, disease control

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INTRODUCTION

Throughout recorded history (and probably long before historical records were kept), human populations trying to establish themselves and live on this planet have periodically been set reeling (and sometimes sent *running*) from diseases borne by insects and other arthropods of medical importance. In fact, when one reviews the records of death and destruction wrought on humans over the centuries by just a few of the major vector-borne diseases that impact our health, one begins to wonder how the concept of man living in harmony with his environment ever got started. Indeed, living on this planet can be very hazardous to the health of humans. Millions, if not billions, of people who have preceded the current generations in life have all died trying to live here, with vector-borne diseases being one of the major contributors to the demise of these past generations of humans. Within the framework of current trends in "politically-correct thinking" and on the basis of the absolute death rate of all humans who have tried to live here on earth, one wonders if we should be trying to save earth or whether we should ban earth, since living here is ultimately lethal to humans and all other forms of life when viewed from the level of the individual of a given species of organism.

The outlandish comments just made are not meant to start a movement toward developing a new environmental policy. They were made, rather, to shock the reader back into a more realistic view of this environment we live in for the moment and to promote the perspective that not everything about the environment which our environmentalist friends want to save is good in terms of human health and well-being -- with vectors and vector-borne diseases being among those factors of the environment that continue to threaten the survival and success of the human species. Those of us blessed by living in areas of the world where the threat of vector-borne diseases is not constantly with us tend to lose sight of the severity of this problem and tend to support policies and approaches toward solving environmental issues that do not take such problems into account. Therefore, it is the intent of this paper to update the reader on the status of certain of the more important vector-borne diseases that continue to impact humans both here in the United States and elsewhere in the world and to give some insight as to what the current trends are in terms of controlling or not being able to control these diseases.

THE GLOBAL VIEW

Data summarized in Table 1 give insight to the current status of the various vector-borne diseases considered by the World Health Organization (WHO) to be the most important on a global basis. It is interesting to note in reviewing these data that, while malaria has been the target of massive eradication programs sponsored by WHO and other national and international agencies for over 45 years now (Harrison 1978, Russell 1950), this disease still remains to be the number one vector-borne disease affecting human populations in the world. In Africa alone, it is estimated that there are at least 35 million human cases of this disease each year (Brinkmann and Brinkmann 1991); and recent economic impact studies indicate that the annual economic burden of malaria in Africa as of 1987 was $0.8 billion. This burden is projected to increase to $1.7 billion by 1995 (Shepard et al. 1991).

The history of malaria, its impact on human health, attempts to control and/or eradicate this disease and reasons for this disease remaining to be the problem that it is have all been subjects of many books, journals articles and other treatises over the years, with the book by Harrison (1978) and the comments by Marshall (1991) being pertinent here. The problems confronted in attempts to prevent, control and, especially, to eradicate malaria in different areas of the world are many, often interrelated and in some instances, too complex to solve at the current time. Some of the major reasons given for the failure of various malaria control programs to meet their objectives are summarized in Table 2 for the information of the reader. These reasons are by no means all inclusive, nor are they ranked in order of their importance. Also,

TABLE 1--Global status of major vector-borne diseases[a].

Disease	Population at risk (millions)[b]	Prevalence of infection (millions)	Present distribution
Malaria	2,100	270.0	tropics/subtropics
Lymphatic filariases	900	90.2	tropics/subtropics
Onchocerciasis	90	17.8	Africa/L. America
Schistosomiasis	600	200.0	tropics/subtropics
African trypanosomiasis	50	(25,000 new cases/year)	tropical Africa
Leishmaniasis	350	12 million infected +400,000 new cases/year	Asia/S. Europe/Africa/ S. America
Dracunculiasis	63	1.0	tropics (Africa/Asia)
Arboviral diseases (Dengue, Yellow Fever, others)	no estimates available	...	tropics/subtropics Africa/L. America E./S.E. Asia

a Source: WHO 1990a, with table adapted from WHO 1990b
b Based on a world population estimated at 4.8 billion (1989)

certain, if not all, of these same reasons may be given to explain why the other vector-borne diseases listed in Table 1 remain to be the problems that they are in the various parts of the world where they occur.

THE PROVINCIAL PERSPECTIVE

While human diseases caused by arthropod-borne viruses ("arboviruses") rank fairly low on the scale of importance from the global perspective (e.g., dengue, yellow fever, and others like Japanese B encephalitis as noted in Table 1), this particular group of disease agents probably ranks close to first as it pertains to the types of vector-borne diseases currently having the greatest impact on human health in the continental United States. Among these agents, the mosquito-borne Flavivirus that causes St. Louis encephalitis (SLE) is now ranked as the leading cause of human epidemic viral encephalitis in the United States (Luby 1979, Monath 1980, Tsai and Mitchell 1989), with the name of this disease derived from the first reported outbreak of the agent during 1933 in St. Louis, MO (U.S. Treasury Dept. 1935).

Since 1933, outbreaks of SLE, studies of these outbreaks, and other epidemiological studies have all combined to indicate that SLE virus is widely distributed in the Western Hemisphere from Argentina to Canada (Monath 1979). In the United States, SLE is considered to be an endemic

TABLE 2--Problems confronted in malaria eradication/control/prevention programs.

- ⊗ Political and social unrest in endemic malarious areas and in areas susceptible to malaria causing disruption of malaria control programs;
- ⊗ Malaria programs in endemic and susceptible areas becoming cost-prohibitive or of reduced priority in public health protection activities;
- ⊗ Increased incidence of insecticide and/or drug resistance on the part of target anopheline vector and Plasmodium parasite populations, respectively;
- ⊗ Ignorance on the part of the general public, political leaders, and scientific and technical personnel as to the specifics of the epidemiology of malaria and its prevention and control;
- ⊗ Lack of technical and scientific personnel with adequate training and experience in malariology to support the needs of malaria control programs;
- ⊗ Build-up of highly susceptible human populations in areas where malaria has been eliminated (e.g., the United States) or successfully abated in endemic areas.

disease west of the Mississippi River; and it periodically occurs in epidemic form in the eastern parts of the U.S., particularly in the Mississippi-Ohio River basin and central Florida (Monath 1979). Also since 1933, there have been at least 50 major outbreaks of SLE in the United States, with the most recent ones occurring in the Central Valley of California in 1989 (CDC 1990b), in Florida in 1990 (CDC 1990d) and in the Pine Bluff area of Arkansas in 1991 (CDC 1991f). It also should be noted that, in each of these years and since the last major outbreak of SLE in the Baytown-Houston Area of Harris County, TX, in 1986 (CDC 1986), evidence of SLE activity and periodically, even some human cases of the disease have been detected in this region of southeast Texas (personal communication, Harris Co. Mosquito Control District).

As noted by Monath (1979), the supporting reservoirs for SLE virus are a variety of passerine birds (e.g., house sparrow and others) and the primary vector species of mosquitoes all belong to the genus, Culex, which show a preference for feeding on these birds. The species of Culex involved as a primary vector for SLE virus varies from region to region in the United States, with Cx. tarsalis Coq., Cx. nigripalpus Theob., Cx. pipiens pipiens (Lin.), and Cx. p. quinquefasciatus (Say) being the most important in the various regions indicated in Figure 1.

Classically, human epidemics of SLE are preceded by a build up of the virus in mosquito/bird enzootic cycles. As the result of the enzootic amplification, the virus spills over via the mosquito vectors, which occasionally feed on humans, into human populations (Monath 1979). Factors leading to this "spill over" vary from region to region; however, some of the primary predisposing conditions leading to urban outbreaks of SLE in human populations include: 1) older neighborhoods where open drainage ditches and peridomestic mosquito breeding sites (e.g., discarded containers, etc.) may be prevalent; 2) open (pier and beam) house foundations, which provide mosquitoes resting sites; and 3) inadequately screened residences without air conditioning (Monath 1980, Tsai and

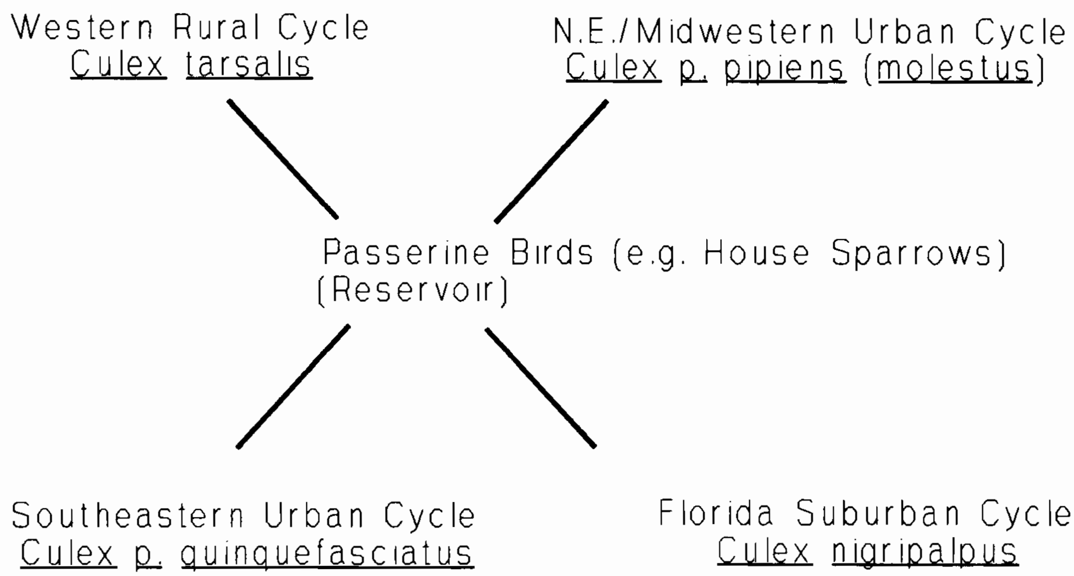

Fig. 1. St. Louis encephalitis cycles in the United States.

Mitchell 1989). To this list might also be added: increased human activity outside during the evening hours when mosquitoes are active, either willingly (e.g., jogging, patio parties, etc.) or unwillingly (e.g., asked to go outside to smoke); the encouragement of birds to enter into yards and nest (via feeders, waterers, bird houses and landscaping); placing insect electrocuting light traps or other types of attractive light sources near to places where humans are present; and other similar types of human activities that would lend to a closer association between humans, birds and mosquitoes feeding on birds (personal observations and personal communication with personnel of the Harris Co. Mosquito Control District). Irrespective of the reasons, when human outbreaks of SLE occur, fewer than 1% of the infections are clinically apparent, with symptomatic illnesses ranging from a febrile, flu-like illness and headache to aseptic meningitis or encephalitis. Advanced age is the most obvious human factor associated with the more severe manifestations of SLE; and mortality (ca. 7% of the symptomatic cases) is greatest in the "chronologically-gifted" segment of our society (Brinker and Monath 1980). Also, effective mosquito management and control strategies are still the only means available to prevent and control outbreaks of SLE in human populations, with the use of safe, effective insecticides against adult mosquito populations being the primary, and often the only means by which outbreaks of this disease can be controlled.

Other mosquito-borne encephalitic viruses that remain to be active in the United States, but which affect human populations on a more limited geographic basis, include the viruses causing California encephalitides (esp. La Cross virus), western equine encephalitis (WEE) and eastern equine encephalitis (EEE), with the latter two affecting horse populations as well as humans (Monath 1979). The most recent outbreak of one of these viruses was the 1991 outbreak of EEE that struck horse populations 7-state area of the southeastern region of the U.S. and human populations in northern Florida, with some of the human cases in Florida dying as the result of EEE virus infection (CDC 1991e).

Turning attention for a moment from on-going vector-borne disease problems to ones that can potentially become problems in the United States, it should be noted that another mosquito-borne Flavivirus, dengue

(DEN) virus, is attempting to make a comeback in our country. Dengue, referred to by such names as breakbone fever, 7-day fever, and southeast Asian hemorrhagic fever as well as dengue fever, occurs throughout the tropical and subtropical areas of the world and has caused extensive epidemics since the 1800s in the temperate zone countries as well (Russell 1976). Several epidemics of this disease are recorded as having occurred in the past in the United States (esp. in the southern U.S.), with the last outbreak occurring in Louisiana in 1945 (Ehrenkranz et al. 1979, Hayes et al. 1971). By the early 1950s, dengue was no longer considered indigenous in the United States, although resurgences of this disease into the Caribbean in 1963 and again in 1977 caused concern about the increased risk of its being reintroduced into the U.S. (CDC 1979a). This concern was justified when, in 1980, several cases of indigenous dengue were diagnosed in human populations located in the lower Rio Grande Valley region of Texas (CDC 1980b). This reintroduction of dengue into the continental United States followed closely after the disease was first detected as occurring in southern Mexico in 1979 and by early 1980, being as far north along the east coast of Mexico as Tampico (CDC 1980a). For reasons still not understood, dengue did not become permanently established in Texas. However, this disease continues to be reported as occurring in Mexico and in other areas of Central and South America as well as in the Caribbean; and additional cases of dengue suspected of being indigenous were again reported in Texas (along the lower Rio Grande River Valley and as far north as Corpus Christi, TX) in 1986 (CDC 1987).

As noted in many issues of the Morbidity and Mortality Weekly Report (MMWR) prepared by the Centers for Disease Control (CDC) covering the status of dengue in recent years, classical dengue (DEN) is an acute viral disease caused by any of four virus serotypes (DEN 1-4). The disease is characterized by sudden onset of fever, headache, myalgia, rash, nausea and vomiting. Although most infections result in relatively mild illnesses, some may cause the more severe forms of the disease, dengue hemorrhagic fever (DHF), which is characterized by petechiae, purpura, mild gum bleeding, nosebleeds, menorrhagia, or gastrointestinal bleeding, and dengue shock syndrome (DSS). As also noted by CDC (1991d), three of the four serotypes (DEN-1, DEN-2 and DEN-4) have been circulating in the Americas since 1981 and the DEN-3 serotype could easily be reintroduced back into this region of the world at any point in the near future.

At the time of the last invasion of DEN virus into the Western Hemisphere (circa 1977), the only vector for the virus known to occur in this part of the world was the yellow fever mosquito, _Aedes aegypti_ (Lin.), a highly domesticated mosquito characteristically breeding in artificial containers in and around human habitations (CDC 1979a). In the United States, this species is widely distributed over a 21-state area of the southeast extending as far southwest as Texas and as far north up the East Coast as New York (Darsie and Ward 1981). Thus, it was this area of the country that was felt to be most vulnerable to the re-establishment of indigenous DEN because of the existing vector support potential. However, in 1985, another known vector for the virus, _Aedes albopictus_ (Skuse), was discovered as occurring in Houston, TX (Sprenger and Wuithiranyagool 1986); and intensified surveys over subsequent years now indicate this species, which is more adapted to overwintering in cooler climates than is _Ae. aegypti_, occurs in at least 113 counties in 17 states to include states as far north as Illinois, Indiana and Ohio (CDC 1989). It is felt that _Ae. albopictus_ was introduced into the United States via eggs in used-tire casings imported from Asia (Craven et al. 1988); and its spread was also most likely supported to a great degree by the tire industry as well.

Irrespective of the means by which _Ae. albopictus_ was introduced or spread in our country, it serves as an example of how vulnerable our nation still is to invasion by new vectors and disease agents they might bear. Also, in regard to dengue, the presence of _Ae. albopictus_ in our country has greatly extended the area vulnerable to the re-establishment of this disease in terms of vector potential. This vector potential is being challenged each year by the importation of active human cases of dengue, particularly by people travelling to areas of the world where this disease is endemic and returning to the United States infected with the virus. For example in 1990, 102 cases of imported dengue were reported to CDC from 24 states and the District of Columbia. Of these, 24 cases from 14 states and D.C. were confirmed as being dengue (CDC 1991d). Since infected humans are themselves the primary reservoir of the DEN virus for mosquito vectors, there is always a potential for such imported cases to go undetected and for the virus to be transferred to locally-breeding populations of Ae. aegypti or Ae. albopictus via the infected individual. Thus, constant surveillance on the part of public health officials for both presence of the vectors and/or the virus is necessary; and it is incumbent on the medical doctors to accurately diagnose diseases that they are treating to prevent the re-establishment of indigenous dengue from happening. Again, the only effective means for preventing and controlling outbreaks of dengue once it has become established in an area is by means of implementing and maintaining effective mosquito management programs targeting the primary vectors of the DEN virus.

Another mosquito-borne disease that has continually tried to make a comeback in the United States since its eradication in the late 1950s and early 1960s is malaria. Human malaria is caused by at least four species of protozoa all belonging to the genus, Plasmodia (Apicomplexa: Sporozoa). Plasmodia vivax and P. falciparum are the most widespread and along with P. malariae, were the ones primarily responsible for human malaria in the U.S. when the disease was endemic and epidemic in this country (Faust 1941). The mosquito species involved as primary vectors for malaria agents in the U.S. were Anopheles freeborni Aitken (previously known as An. maculipennis Meigen) in the west and An. quadrimaculatus Say in the eastern and southern portions of the country, with other anopheline species involved in malaria transmission on a more local basis (Matheson 1941). These same anopheline species complexes continue to occur and thrive today in many of the same areas of the United States where they were found during the malarious years (Darsie and Ward 1981, Faust 1941) and stand to provide vector support for the local spread of malaria if and when they are exposed to active human cases of this disease.

The primary means by which malaria can be and in some instances, is being reintroduced into the United States are summarized in Table 3. The information in this table was derived from a variety of sources to include CDC (1981, 1982, 1984, 1990e, 1991g), Haworth (1989) and Maldonado et al.

TABLE 3--Means by which malaria is being reintroduced into the United States.

- ⊗ By U.S. citizens returning from trips to areas where malaria is endemic (military personnel, business people, tourists, etc.: active cases/relapses)
- ⊗ By migrant workers entering U.S. from areas where malaria is endemic
- ⊗ By people immigrating to the U.S. from areas where malaria is endemic (legally and illegally)
- ⊗ By people seeking malariotherapy as treatment for other diseases (e.g., treatments for neurosyphilis, neuroborreliosis, etc.)

(1990). These same sources were used to prepare Table 4, which summarizes the causes or sources of locally-acquired cases of human malaria that have been reported as occurring in the United States in recent years. Of

TABLE 4--Sources of locally-acquired malaria in the United States.

- Contaminated blood transfusions:
  - Accidentally: e.g., during medical treatments or acts of drug abuse
  - Purposely: e.g., malariotherapy
- Congenital transmission
- Autochthonous transmission of introduced malaria
  - In the laboratory: e.g., accidental transmission during experimentation
  - In the field: e.g., as has occurred recently in California and New Jersey

particular note in this regard are the in-country cases of malaria that were locally-acquired via infected mosquitoes (autochthonous transmission of introduced malaria) in the Central Valley of California in 1980 (CDC 1982), in San Diego County, CA in 1986 (Maldonado et al. 1990) and most recently in New Jersey (Crans 1991). These particular cases serve to remind us that we here in the United States are still vulnerable to malaria and vigilance must be maintained to insure that this disease does not become re-established to any significant degree. Also, while guarding against obvious ways malaria can be reintroduced into our country, we must take into account the unlikely ways as well. For example, there have been at least two instances in recent years where people have had themselves purposely infected with P. vivax via infected blood injections in an attempt to rid themselves of the borrelial agent that causes chronic Lyme disease (CDC 1990e, 1991g). This use of malariotherapy for the treatment of neuroborreliosis is truly a case of "the treatment perhaps being worse than the disease" and certainly is an unexpected way for malaria to be cryptically reintroduced back into various areas of the United States.

With the mention of neuroborreliosis, attention will now be turned to some of the more important tick-borne diseases occurring in the United States, with Lyme Disease caused by the spirochetal agent, Borellia burgdorferi, currently being the one of greatest concern to the general public. In actuality, Lyme disease, also known as erythema chronicum migrans (ECM), has probably been in the U.S. for a much longer period of time than scientific and popular press articles would indicate. ECM has been reported as occurring in Europe for many years (Glotz 1971); but, it was only in 1975 that a clustering of ECM cases occurring in three contiguous towns adjacent to the lower Connecticut River (i.e., Lyme, Old Lyme and East Haddam, CN) caused scientists to suspect that this disease was also established in the United States (Steere et al. 1977a, b). Also, the frequency with which ECM cases were associated with recent tick bites caused the suspicion that ticks might, indeed, be vectoring the causal agent of ECM (Steere et al. 1978, CDC 1979b). Subsequently, extensive epidemiological investigations of the disease, as it occurred in Connecticut and elsewhere, revealed that ECM was in fact a tick-borne disease and that the causal agent was a previously undescribed spirochete to which the name, Borrelia burgdorferi, was given in honor of Dr. Willy Burgdorfer, who first discovered the spirochete in infected ticks (Schmid 1985, Steere et al. 1983).

The epidemiological picture for Lyme disease is not yet complete and the full extent of its occurrence and impact on human health in the United

States have yet to be fully clarified. What is known thus far is that this disease is a zoonosis (i.e., a disease of other animals transmissible to humans), with deer (esp. white-tailed deer) and rodents (esp. white-footed mice) appearing to serve as reservoirs for the causal agent. Birds also are involved in the widespread dissemination of the disease (Anderson et al. 1986) and there is evidence of contact transmission of the disease among white-footed mice (Burgess et al. 1986). Ticks themselves may add to the endemicity of Lyme disease via transovarial transmission of B. burgdorferi from female tick to offspring (Piesman et. al. 1979). The primary tick vector for B. burgdorferi in the coastal areas of the northeastern U.S. and in the upper midwestern states is Ixodes dammini n. sp. (Steere et al. 1978), which was described as a new species by Spielman et al. (1979). Ixodes pacificus Cooley and Kohls is the primary vector along the west coast of the United States (Burgdorfer and Keirans 1983); and Ixodes scapularis Say is considered to be a primary vector for the Lyme disease agent in the southern part of the country (Oliver 1989). Other tick species that have been incriminated as possibly being involved in the cycling of B. burgdorferi include Amblyomma americanum (Lin.) (Schulze et al. 1984), Dermacentor variabilis (Say) and Rhipicephalus sanguineus (Latreille) (Rawlings 1984). The recognized vector for ECM (Lyme disease) in Europe is Ixodes ricinus (Lin.), although one ECM case occurring in Europe was outside the range of this tick species and was ascribed to mosquito bites (Schmid 1985).

Human infection by B. burgdorferi is usually signaled by the appearance of a rash within a month after a person is fed on by an infected tick. The pattern of the rash is characteristic in that it encircles the location of the tick bite giving it a red bull's eye appearance with a clear center. This circular rash may expand to cover an extensive portion of the body region in the vicinity of the tick bite. Even after the rash appears, the disease is easily cured by antibiotics (e.g., tetracyclines, penicillin or erythromycin) if it is detected early. Unfortunately, the rash does not occur 30% of the time and detection and proper diagnosis of the disease is then made more difficult. Beyond the rash being present or absent, individual cases of Lyme disease can vary greatly in severity. Some victims feel no more discomfort than if they had a mild case of the flu. Others develop nausea, stiff neck and inflamed joints with pain similar to that of arthritis which can become chronic. In some cases, the disease in its later stages can result in cardiac abnormalities (Steere et al. 1979). The agent can also invade the nervous system producing symptoms like those of meningitis and encephalitis (Poullot et al. 1987, Hanny and Hauselmann 1987).

As for the geographic distribution of Lyme disease in the United States, 46 states reported cases of this disease in 1989 and 1990, although the occurrence of the caustive agent in nature was not confirmed in all of the states reporting cases (CDC 1991b). The zones of highest incidences of cases being reported include the upper Atlantic Coast states (Connecticut and states surrounding it), the upper midwestern states (Minnesota, Michigan and states surrounding them), the southeastern coastal states (Georgia and surrounding states) and California.

The total number of Lyme disease cases reported in the United States for 1989 was 8803 and the provisional total of cases for 1991 was 7997 (CDC 1991b). The number of cases reported in 1989 represented an 18-fold increase over the number of cases reported in 1982 (497 cases) when CDC began its coordinated Lyme disease surveillance program. This increase in number of cases probably should not be considered as much evidence of an outbreak of Lyme disease in our country as it should be considered evidence of what impact the discovery of a disease's presence, increased scientific and diagnostic/surveillance activities, and "mass media hype" will all have on case reporting data for a newly-detected disease in a country like ours. As noted by CDC (1991b), the provisional total of 7997 Lyme disease cases in 1991 might represent a plateau in the trend of rapid annual increases and if this trend holds, may represent the annual case rate that has been going on in this country for some time before this disease's presence was detected. In its 1990 report to CDC, the Wisconsin Division of Health (WDOH) noted a 54% decrease in total Lyme disease cases as compared to 1989 (CDC 1991b). The suggested reasons for this sharp decrease in reported cases given by WDOH were: "1) a decrease in media coverage of Lyme disease; 2) a decreased prevalence of *I. dammini* ... in that region, based on anecdotal reports from entomologists to WDOH; and 3) success of educational efforts to prevent tick bites." WDOH also noted a decline in the use of commercial and reference laboratories for Lyme disease serological diagnoses, which may reflect a true decrease in Lyme disease incidence in the state, the change in medical practices concerning this disease, or other factors yet to be revealed (CDC 1991b).

Strategies for preventing and controlling Lyme disease are still in the process of being worked out. For the moment, education of the public as to how to take precautions when they go out into areas potentially infested by ticks is the primary strategy. A variety of other strategies are being researched as to their efficacy, environmental impact and/or economic feasibility in regard to either preventing humans from being infected in Lyme disease endemic areas or to reduce tick vector populations below the densities needed to support the continued endemicity of the disease (Oliver 1989). The primary strategies currently being used or researched for possible use against Lyme disease in the United States are summarized in Table 5 for the information of the reader.

TABLE 5--Strategies used (+) or being developed (?) for the prevention and control of Lyme disease (LD) in the United States and elsewhere.

+	Public and professional education on LD symptomology and epidemiology
+	Public education on how to avoid tick bites
?	Habitat modification directed against ticks and/or their natural hosts
?	Reservoir/Vector elimination e.g., Mouse and/or deer removal or exclusion; Chemical treatment of premises against ticks; Distributing chemically-treated nesting material for mice to control ticks on mice and in nests.
?	Antibiotic prophylaxis of recognized human tick-bite cases
+	Early diagnosis and treatment of active human LD cases

Aside from Lyme disease, there are several other zoonotic diseases supported by tick vectors that have been known to occur in the United States for many years and which continue to impact the health of humans living, vacationing and/or touring in various parts of our country. Information regarding the status of some of these other tick-vectored diseases is summarized in Table 6.

There are many other arthropod-borne disease that are either endemic in the United States or threaten entry or reentry into this country from other parts of the world (e.g., flea-borne plague caused by the bacterium, *Yersinia pestis*, is still endemic in certain areas of the southwestern and western U.S. and yellow fever virus is still endemic and active in Central and South America as well as in Africa). However, the diseases just presented and discussed are enough to demonstrate the fact that the United States is far from being free from the threat and ravages of these kinds

TABLE 6--Status of some other tick-vectored diseases in the United States.

Rocky Mountain Spotted Fever (RMSF)	
Causal agent:	Rickettsia rickettsii
Present status:	Circa 600 cases/year in the U.S. (esp in the south Atlantic and west south central states)
References:	CDC (1990a, 1991c), Taylor (1991a)
Tick-borne (Endemic) Relapsing Fever (TBRF)	
Causal agent:	Borrelia hermsii, B. turicatae and other Borrelia spp.
Present status:	Most recent outbreaks include those in Grand Canyon National Park (1973, 1990) and at Big Bear Lake, San Bernadino, CA (1989)
References:	CDC (1979c, 1990c, 1991a)
Tularemia	
Causal agent:	Francisella tularensis
Present status:	100 to 300+ cases/year (esp. in the west south central states)
References:	Taylor (1991b)
Human Ehrlichiosis	
Causal agent:	Ehrlichia canis or a closely-related species
Present status:	First recognized a disease of humans in the U.S. in 1986, with over 100 human cases thus far reported (esp. from west south central and south Atlantic states)
References:	CDC (1990a), Anon. (1991)

of diseases on human health. Thus, while public and political attention is now being more focused on the "ills of this generation" (e.g., heart disease, cancer, A.I.D.S., environmental pollution and destruction, and a variety of psychoses spawned by urban living and current life styles), care must be taken not to lose sight of one of the primary means by which "nature" has previously regulated the location and population growth rate of humans on this planet; i.e., via such factors as vector-borne disease. Further more, having sight on the problem is one thing; being able to do something about the problem is quite another. Therefore, all efforts must be made to preserve our nation's ability to respond to vector-borne disease problems via the development, implementation and maintenance of effective disease/vector management and control programs and to otherwise protect the public health against these diseases and the vectors that bear them -- a subject addressed in the next section of this paper.

STATUS OF VECTOR/VECTOR-BORNE DISEASE CONTROL PROGRAMS IN THE UNITED STATES

From the standpoint of effectively controlling or at least managing vectors and the diseases they bear, the United States has enjoyed a long and glorious history of successes, with organized efforts to systematically control mosquitoes and mosquito-borne diseases being among the earliest to be implemented in this country (First Anti-Mosquito Convention 1903, Howard and Bishopp 1932). These organized programs were, for all practical purposes, based on the principles and concepts of what

TABLE 7--Elements of an integrated arthropod-related pestilence management program.

1. Knowledge of:

    a. The bionomics of the pest(s) or vector(s) involved
    b. The epidemiology of the disease involved

2. Survey/monitoring effort for the detection and status assessment of:

    a. Pest(s) or vector(s) involved
    b. Pathogen, reservoirs and susceptible host involved

3. In-depth prevention/control program comprised of a system of tactics effective against:

    a. Target pest or vector populations
    b. Target pathogen populations and the vertebrate host complexes supportive of the pathogen's continued cycling in a given area

4. Continuous program evaluation and modification (cost/risk/benefit assessments vs. tactics and their success in meeting program objectives)

5. Educational activities:

    a. Public education, to create awareness, understanding and support
    b. Professional/technical training, to keep professional and technical staff up to date on the technologies and tactics being used

has now become known as integrated pest management (IPM) and served as a basis for developing similar programs for other vectors and diseases of importance to human health for use in this country as well as in other parts of the world. The relationship of organized or comprehensive vector control programs to the concepts and principles of IPM are otherwise discussed by Olson (1979); and the elements basic to any organized, integrated management or control program directed against a pestilence, be it arthropod-caused or arthropod-borne, are summarized in Table 7. These elements represent a compilation of the author's own professional experiences and observations and those of others as documented in such publications as those by the American Mosquito Control Association (AMCA 1990), the President's Council on Environmental Quality (CEQ 1979), and the National Academy of Sciences (BOA/NRC 1972, BOSTID/NAS 1973, ESB/NRC 1976, BOSTID/NRC 1983).

Public, political and federal support for the control and prevention of vector-borne diseases and the vectors involved appears to have reached its peak in the United States during and for approximately 25 years after World War II. The focus of attention in the early years of this rise in support was malaria, with the U.S. Public Health Service establishing the offices of Malaria Control in War Areas (MCWA) in Atlanta, GA, during 1942. MCWA was charged initially with the execution of malaria control in the "extra-cantonments" of military and war industrial areas of the U.S.; but, by the end of the war, the agency had expanded its effort to include control of a number of other vector-borne diseases as well (Hollis 1946). By the late 1940s, MCWA was liquidated and demobilized in favor of a new

U.S. Public Health Service center based in Atlanta which was designed to broaden the efforts of USPHS in the whole field of tropical and related diseases. This center was to become known as the Communicable Disease Center and later, as the Centers for Disease Control (CDC). Initially, CDC had four main service functions as it related to vector-borne disease control in the U.S. As outlined by Hollis (1946), these functions included:

1) Training: to include vocational internship type training of public health personnel, the production and distribution of audio-visual and other training aids, and the establishment of a diagnostic reference and training laboratory and library.

2) Epidemiology: to include specialized epidemiological services to states in need of such services, such as the definition and elucidation of the epidemiology of specific diseases and the conduct of laboratory and field studies of tropical and related disease problems and how they might best be controlled.

3) Technical development: to include the development of equipment, materials and operating techniques for improving field control measures, and conducting biological and engineering investigations, with emphasis on insects as related to public health.

4) Field operations: to include the conduct of cooperative tropical and related disease control demonstrations with state health departments, provision of technical consultation services to state health departments and other agencies, provision of operational assistance in emergencies and provide support for other operations as might be prescribed by Public Law.

As those familiar with history of CDC can attest, this agency provided the strength, focus and leadership that was necessary to deal with a number of vector-borne diseases that continued to impact the health of humans after World War II in the United States. These diseases included not only malaria (Bradley and Lyman 1951, Andrews 1951), but also yellow fever (Schliessmann 1964), murine typhus, sylvatic plague (Hollis 1946) and the mosquito-borne encephalitides (Bradley and Lyman 1951). However, as those familiar with the history of vector-borne disease control in the U.S. can also attest, priorities within the U.S. Public Health Service, and particularly at CDC, began to shift away from vector-borne diseases in the mid- to late 1970s to other diseases deemed at the time to be of higher priority and greater concern. These diseases included cancer, heart disease, nutritional diseases, other communicable diseases of concern and eventually, A.I.D.S. This shift in priorities has severely weakened CDC's ability to continue to respond to its mandates in regard to vector-borne diseases and has placed more of the responsibility for dealing with these diseases now on state and local public health and vector control agencies. It should also be noted that a similar shift in priorities and a down grading of priorities regarding vector-borne diseases began to occur in the WHO during the late 1980s, as was marked by the dissolving of this agency's Division of Vector Biology and Control in 1989. Malaria control and eradication programs, again, were an integral and important aspect of this international agency's mandate when it was first formed in 1947 (Russell 1950). Malaria control still remains to be on the agenda of activities supported by WHO. But again, diseases such as A.I.D.S. and other socioeconomic concerns that impact the public health of developing countries have been given either equal or higher priority and compete with malaria and other vector-borne disease control programs for the limited resources available to WHO for the support of its overall effort.

In regard to vector and vector-borne disease control activities at the state and local levels in the United States, a survey recently completed by the American Mosquito Control Association (AMCA) identified the existence of at least 1,071 agencies that were involved in vector control in the U.S. and Canada as of 1990 (AMCA 1991). This total represents an overall increase of 332 agencies as compared to similar data gathered in 1980; and the total amount of money being spent by these agencies annually increased from $84,099,556 in 1980 to $156,292,430 in 1990 (AMCA 1991). The focus of these surveys was on identifying vector control agencies that were concerned primarily with mosquito control, but many of these same agencies deal with other vectors of disease as well.

On the surface, the data regarding the current status of vector control in the United States give the impression that the state and local governments have risen to meet the challenge in regard to the reductions in support for the study and control of vectors and vector-borne disease at the federal level. In certain instances, this is true; but, it is the impression of this author that in many other instances quite the opposite is true. First, as a former president of AMCA, the author has first hand knowledge that the AMCA survey conducted in 1990 was much more thorough and aggressive in its execution than was the one conducted in 1980. Therefore, the increases shown in numbers of agencies and amount of money spent may, and probably are to some extent, artifacts resulting from the different manners by which the two AMCA surveys were conducted. Also, in observing changes in the status of local vector control agencies of the past 20 years in his own region of the United States (i.e., the Texas-Louisiana region), the author has seen either a plateauing of effort or, in some instances, a reduction or elimination of effort due to either reductions in budgets or increases in budgets that were not comparable to rises in operational costs caused by inflation. Also, the legalities imposed on vector control agencies (e.g., liability insurance, workman's compensation, environmental regulations, etc.) have taken their toll on the ability of local and state agencies to maintain effective vector control programs. In addition, it is the impression of this author, that, with the effective abatement and/or elimination of vectors and the diseases that they bear, the public perception in the United States as to the need for continuing to support vector control activities to the level that it has in the past is shifting downward in favor of other problems that are of more immediate concern(see Olson 1984). Correspondingly, the political support for such programs is waning; and where the political support goes: so goes the money. In certain instances, local governments have attempted to solve the problem of maintaining vector control programs in the face of a dwindling base of tax dollars and increased demands for other services by contracting some or all of their vector control activities out to private companies so as to cut overhead costs. At the moment, there is a great debate going on, at least in Texas and Louisiana, as to whether or not this approach to maintaining vector control services is truly effective, or economical for that matter.

Aside from changes in public and political perception as to the continued need for vector and vector-borne disease control programs, there are a number of other socioeconomic factors or trends currently prevailing in the United States which, from this author's viewpoint, stand to have an increasing negative impact on the ability of local and state agencies to continue to provide effective, economical vector and vector-borne disease control. These factors or trends include:

1) <u>Bases upon which decision are being made</u>. With the urban intellectualism that currently prevails in the decision-making processes regarding policies and programs impinging on vector control in our country, decisions regarding the environment are being made without taking the negative aspects (i.e., the naturally-existing environmental resistance factors) that impact human health and economy into full and proper account.

The general public, and its politicians for that matter, are perceived by this author to be, for the most part, unaware or ignorant of the naturally-occurring negative aspects of the environment. With such ignorance, comes the ability of activist groups to sell their environmental agendas without regard to the truth or facts regarding all the complexities of the matter in question. Such ignorance provides an opening for fear-causing activism and reactivism to govern policy-making and we, as a people, become subject more to governance by the "creation of perceived crises" rather than by the real crises that already exist.

2) **Chemical resistance**. There are two forms of chemical resistance that vector/vector-borne disease control specialists are currently having to face: i.e., vector and pathogen resistance to the chemicals being used against them and human resistance to the use of chemicals in general ("chemophobia"). The latter form of resistance is becoming just as important as the former one in terms of its hindering or preventing effective vector/vector-borne disease programs. Again, the public perception being set in this country by activism is that all chemicals and their uses (irrespective of the reason) are "bad" for humans and for the environment in which we live. The fact is that, in certain instances and as previously mentioned, the prevention and control of outbreaks of many vector-borne diseases affecting human health are still contingent on the availability and use of effective chemicals, be they pesticides or chemoprophylactic and/or chemotherapeutic agents. The promises of biotechnology to provide the world with alternatives to the use of these chemicals (e.g., new biological control agents, safer bio-pesticides, vaccines, etc.) have yet to be realized. Thus, while they wait for these promises to be fulfilled, vector-borne disease control specialists must continue to have at their disposal chemicals which are effective and the freedom to use these chemicals to continue to provide protection to the public and its health. It should be noted here that vector control specialists view their insecticides they use much in the same manner as medical doctors view their drugs. In the hands of a well-trained professional (one knowledgeable and proficient in how, when and where a given insecticide should be applied for maximum effect and minimum environmental damage), an insecticide is no more dangerous than many of the drugs that doctors prescribe for use in our bodies. However, in hands of a person not so trained and knowledgeable, an insecticide can be just as dangerous as a human pharmaceutical when it is misprescribed or misused. Therefore, the problem experienced with insecticides have, for the most part, been the result of drug misuse or drug abuse, much in the same way that problems with drugs prescribed, sold over the counter or produced illegally for direct use by humans to treat physical or psychological ailments have occurred. The problem is not as much the chemical, but rather it is the person irresponsibly prescribing or using the chemical who is the true source of the problem.

3) **Dwindling arsenal of effective control agents**. Chemical resistance, environmental regulations limiting or banning the use of certain chemicals, and reticence on the part of the private sector to develop, produce and/or market new chemicals and other control agents for use in vector/vector-borne disease programs have all combined to reduce the number of such agents still effective and/or available for use in the United States to a very low, critical mass. Chemically-

speaking, there are but a handful of insecticidal compounds still available for use against vector populations; with organophosphates, such as malathion, chlorpyrifos, naled and temephos, and synthetic pyrethroids, such as resmethrin and permethrin, being the ones most commonly used against mosquitoes and other vectors in the United States at the current time. Among the chemicals classified as insect growth regulators (IGRs), methoprene is the only one currently being used on a large-scaled basis for mosquito larval control, while the use of various oils (e.g., diesel oil and other petroleum-derived surface film compounds) for mosquito larval control is on the decline in the U.S. (AMCA 1991). The actual amount of chemical toxicants used annually in the United States for mosquito control alone is approximately 6.7 million pounds (AMCA 1991) as compared to approximately 97.0 million pounds of insecticide being used for agricultural purposes annually (BOA/NRC 1989). This computes to approximately $69 million of insecticide being purchased annually for mosquito control, while approximately $1.0 billion is being spent annually on the purchase of insecticides for agricultural uses. Thus, the market for insecticides designed specifically for vector control is limited; and this limited market, coupled with what it now costs a company to develop a new chemical for such a use ($50 to $60 million from discovery of the molecule to full registration), goes a long way in explaining why there is a reticence on the part of the private sector to develop new agents of any kind for use against vectors in the United States. Also, it costs a company approximately $6.0 million to reregister an existing insecticide when its label expires; and this may cause some chemicals currently being used for vector control to be lost if the reregistration costs exceed the projected market value of the chemical agent in question. Such has already happened in the case of the temephos and its label for use against black fly larvae in the United States.

While the problems just discussed are already having some effect on the capability of vector and vector-borne disease control agencies to continue to protect public health in the United States, this nation still has in place a network of state and local programs that are, for the most part, able to respond to the needs of its citizens. The challenge to this nation and its leadership, as well as to the vector/vector-borne disease agencies themselves, is to insure that this capability to respond is not weakened further. In this regard, vector control specialists realize that, while their primary mission is protecting people, they have a responsibility of protecting the environment as well. Thus, in the interest of preserving both their programs and the environment, vector control agencies have made a concerted effort in recent years to reduce their dependence on chemical pesticides in favor of using bio-rational or nonchemical control tactics whenever and wherever possible. For example, use of the environmentally-safe bacterial toxin produced by Bacillus thuringiensis var. israelensis (Bti) by vector control agencies for the control of mosquito larvae in the U.S. rose from no use in 1988 to an annual use of almost 838,000 pounds of granular product, almost 204,000 gallons of liquid product and slightly over 57,400 Bti briquettes by 1988 (AMCA 1991). Also, this author has been involved in a cooperative research project which recently developed a strategy for using Bti against the southern buffalo gnat (Cnephia pecuarum Riley) larvae in the river drainage systems of East Texas (unpublished data). It should be noted further that the use of fish against mosquito larvae has long been practiced as a biological control tactic here in the United States, with over 50,000 pounds of the mosquitofish, Gambusia affinis (Baird and Girard), and over 100,000 individuals of other fish species currently being used annually for this purpose in the U.S. (AMCA 1991). A number of other biological control agents showing promise for use against various disease vectoring insects are currently in the process of being researched as to their efficacy, efficiency and safety for use in the United States (AMCA 1985).

The other aspect needing attention in the interest of preserving our nation's ability to respond to vectors and vector-borne disease problems is education. As noted in Table 7, education of both the general public and its leaders about the true nature of the environment we live in and the means by which humans can be protected or protect themselves from natural factors of the environment that threaten their health is just as important in an organized vector-borne disease management program as is the education of the technical and scientific personnel that are involved in executing the management program. Unfortunately, public education regarding vector-borne disease and their abatement or control has not received the attention in the United States that it probably should have in recent years. When diseases such as malaria, yellow fever, dengue and plague were prevalent in the U.S., they in themselves served as the public's educators and their impact on human health was a topic carried by most mass media outlets of the time. However, now these diseases are no longer a topic of concern, human interest or awareness about the existence of such diseases has correspondingly waned. Therefore, it is left to public educators and specialists involved in the prevention and control of vectors and vector-borne disease to raise the public's awareness back up to a level where it comprehends and supports the need for the continuance of effective and responsive programs in this area of preventive medicine. Along with this challenge, education programs must continue to exist that will train the scientific and technical support needed by the United States and other countries to sustain existing vector-borne disease control programs and to develop new ones as they are needed. As was brought out in the workshop and study sponsored by BOSTID/NRC (1983), education is probably the most important facet of vector-borne disease control in need of attention as we humans head for the 21st century.

SUMMARY AND CONCLUSION

While the information and comments presented herein are not all inclusive in regard to the topic at hand, they hopefully will lend to a clearer understanding that vectors and vector-borne disease still present themselves as an imposing threat to the health and well-being of humans attempting to live on this planet and that even the United States is not exempt from this threat. Also, it should be obvious that, in order to protect humans from the ravages of vectors and the disease agents they bear, effective and efficient control programs will continue to be needed both in the United States as well as in other parts of the world. Scientific and educational support from these control programs is in need of continuance as well. Above all, however, public support for these programs is an absolute requirement; for, without the support of the public and its politicians, the rest of the needs will go unsatisfied or only partially fulfilled.

As has often been our history in the United States, the organized, vocal minority currently has the ear and conscience of our nation; and the unorganized, silent majority is finding what it considers to be important being pushed aside in favor of those issues supported by the vocal few. One of these issues being pushed aside is the issue of being able to sustain programs that are responsive to the vector and vector-borne disease control needs of this country. A concerted effort must, therefore, be made to re-establish this issue as a priority item on our nation's agenda. It is the hope of this author that it will not be an outbreak of a vector-borne disease that does this; but, this may well have to be. The polities of the "laws of nature," to which some of our activist friends would have us espouse, have a way of reminding us that, as a life form on this planet, we humans are subject to the same rules as any other life form and that "survival of the fittest" is a fact of death as well as life. History proves out that the fitness of humans to live here better and longer has rested more on our ability to perceive problems and to solve or prevent these problems from happening than on our genetics and ability to adapt. Vectors and vector-borne diseases are one group of the "problems" of living (or dying) with nature that will continue to require our undivided attention if we, as a species and as individuals, are to end up on the right side of the survival ledger as governed by natural law.

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URBAN PEST MANAGEMENT IN THE 1990'S

David H. Naffziger

Technical Director
Whitmire Research Laboratories
St. Louis, Missouri

ABSTRACT - The technology of the synthesis of organic compounds has provided numerous benefits to modern society, including more leisure time and longer, healthier lives. One problem is that our society has been convinced by "toxic terrorists" that this new technology is dangerous. These individuals have convinced a large portion of the population that pesticides are dangerous and deadly. We must begin to become proactive and take the high ground in regards to the "toxic terrorists". The people of the pest control industry are the protectors of the environment. Changes that will occur in the professional pest control industry include new active ingredients, products specialized for specific insects, and more restrictive label.

Keywords - regulation, environment, pest control, future

Introduction

Last September I was in front of an alchemist's laboratory at the The German Museum in Munich, Germany, when it suddenly came to me that this is where it all started. It was from these laboratories that came the technology that produced our modern society, and all of it conveniences. The experiments that alchemists were paid to conduct was to covert lead into gold. As these people worked in the laboratory, they slowly realized that lead could not be converted into gold. However, the experiments they conducted during the time they were not working on this process produced other positive results that led to the basis of modern chemistry. As this chemistry improved during the 18th and 19th centuries, the stage was set for the breakthrough reaction which was conducted by Prof. Wohler in 1828. This breakthrough involved the reaction of ammonia with carbon dioxide under pressure and high temperature to produce urea. This reaction involved the use of two inorganic gasses to produce a solid material. The miracle of this reaction was that the first synthetic organic compound was produced. This new type of chemistry led to the production of hundreds of other organic compounds which, with the other breakthroughs of the industrial revolution, created modern society. This head start is still seen today in Germany's large and powerful chemical industry.

Environmental Issues

Before the widespread synthesis of organic compounds, inorganic compounds had been used as pesticides and drugs. The options presented by these products were limited. The new technology produced many benefits, including more leisure time and longer, healthier lives. The problem is that our society has been convinced that this technology is dangerous. The "toxic terrorists" have convinced themselves, and a large portion of the population, that pesticides are not just dangerous, but deadly. The point of this presentation is that these "toxic terrorists" are causing drastic changes in our society, and out industry, to which we must adjust in the coming years.

We must stop reacting to the "toxic terrorists" and begin to be proactive. We must take the high ground., We, the pest control industry, are the modern-day environmentalists. The "toxic terrorists" have proclaimed themselves the founders of the environmental movement and defenders of the environment. This simply is not true. The people of this industry are the protectors of the environment in ways too numerous to list. We are the developers and practioners of the technology that protects our food supply and personal health. Therefore, as Norm Cooper, current President of the National Pest Control Association, proclaimed at the 1992 Purdue University Pest Control Conference, "We are the environmentalists" should be the these of the pest control industry for the 1990's.

Changes

The changes that we will encounter are not the result of of real science, but perceived as reality. As was presented earlier at this conference by Ron Sbragia of DowElanco, they are emotional issues. This means more well-intentioned, but sometimes misguided, government regulation. This is apparent in the termiticide application, where states are trying to analyze treated soil to determine if an adequate application has been made. The indoor air pollution studies undertaken by the Environmental Protection Agency are also of concern. The studies that have been completed on indoor air pollution have detected pesticides in the indoor environment, but a extremely low levels. The problem is that pesticides have been detected at all, since the "toxic terrorists" have convinced the world that one molecule of any pesticide is deadly. The indoor application of pesticides will come under more scrutiny. If the "baseboard jocky" is not extinct, we will soon be in serious trouble. We must realize that this issue is reality and adjust our product selection and application technology very carefully when controlling insects and other pests.

All of the pressure on our industry will result in other changes over which we have little or no control. Costs are a serious concern. As federal, state and local costs increase, costs will escalate. Technicians will be required to be carefully trained and certified. Equipment, as well as supplies of all kinds will continue to cost more. This will all lead to the inability of this industry to make as many treatments as presently practiced. We have all heard about quarterly treatments, but there are companies advertising once-a-year treatments. What is your plan to deal with these changes? We should be developing the plans for these changes as an industry, not waiting to see "how it will become."

New pesticide active ingredients and delivery systems will continue to be developed. However, this development will be slow and costly. New products will be more specialized. By this I mean, products will be developed for the control of specific insects. Chlorox's MaxForce pharaoh ant bait and Whitmire's Avert cockroach bait are examples. The large, broad labels of diazinon and carbaryl are a thing of the past. In fact, if a present day label for these products was compared to a lable of ten years ago, a large decrease in the claims made on these lables would be noted.

One of the less obvious changes needed is related to the fact that in the United States we have 281 lawyers per 100,000 people and in Japan there are 11 lawyers per 100,000 people. How can we expect to compete in a world economy with this 270 persons per 100,000 albatros around our necks. There must be some recognition that regulation is proper and acceptable, but that regulation out-of-control is unhealthy for our economy.

Conclusions

In closing, I must say that I consider the prognosis for our industry in a very positive light. People will not easily give away the lifestyle that we enjoy in the United States. In addition, people are always going to have entomophobia and demand a pest-free environment. Our charge is to provide this service in a safe, professional manner.

THE EFFECTS OF TEMPERATURE AND HUMIDITY ON SURVIVAL AND FEEDING RATES IN THE WESTERN DRYWOOD TERMITE *Incisitermes minor*

Brian J. Cabrera and Michael K. Rust
University of California, Riverside

The effects of temperature and humidity on various economically important termite species have been studied but there have not been any thorough investigations of these abiotic factors conducted on *Incisitermes minor*. The research presented is part of an overall study of the effects of temperature and humidity on survival, feeding, behavior, and differentiation in *I. minor*.

Groups of one hundred *I. minor* nymphs were kept at combinations of the following temperatures (15.6, 21.1, 26.7, and 32.2°C) and relative humidity (32.5, 55 and 75% RH). The groups were divided into 5 replicates with each replicate consisting of 20 nymphs placed in a small covered plastic cup containing a 3.1 cm. x 3.1 cm. x 2.0 cm. block of Douglas fir. Each block was precut into three wafers measuring 3.1 cm. x 0.67 cm. and held together by a plastic screw and wing nut. The nymphs were allowed to feed on the blocks. The termites, blocks, and frass produced were weighed separately every 2 weeks and the number of dead termites was counted.

Results at 13 weeks indicate that mortality decreases at each temperature with increasing RH. Mortality was greatest at 32.2° C at 32.5 or 55% RH and lowest at 32.2° C at 75% RH.

Percent weight loss in termites is greatest at 32.2° C at 32.5% RH and lowest at 32.2° C at 75% RH. Weight loss was highest at higher temperatures. Moderate temperatures with higher humidity appears to be the most conducive for long-term survival and growth of *I. minor* nymphs.

Results from this research in combination with behavioral studies and in relation to temperature profiles from within buildings may provide information that can be used to improve control methods for *I. minor*.

FORMOSAN TERMITE SWARMING BEHAVIOR

Gregg Henderson
Louisiana State University Agricultural Center
Dept. of Entomology, Baton Rouge, LA 70803-1710

The month-long flight season of Formosan termites is thought to be controlled by climatic factors. Evidence of this is revealed by light-trap collections in New Orleans, Louisiana (1989 and 1991). However, a peculiar flight pattern within this swarm season indicates that flight behavior is also controlled by factors intrinsic to the colony. Both the Louisiana data and earlier reports from Hawaii show a two week lull period between peak flights (> 1,000 individuals trapped). The regularity of the second flight time cannot be attributed to weather conditions. Application of these findings may allow us to predict the timing and magnitude of the swarms and to introduce a control strategy that takes advantage of the behavioral pattern.

DISTRIBUTION OF SUB-SLAB INJECTED XRM-5160 IN SOIL

Shripat T. Kamble, Robert W. Davis
Environmental Programs
University of Nebraska, Lincoln, NE 68583

and

Mike P. Tolley
DowElanco
9002 Purdue Rd., Indianapolis, IN 46268

Horizontal and vertical distribution patterns of XRM-5160 (chlorpyrifos) in silty clay loam and loamy sand soils were measured. Fourteen plywood cubes (1.2 m X 1.2 m X 0.6 m) were constructed. Seven cubes were filled with silty clay loam and the remaining seven cubes with loamy sand at a soil compaction rate of 1.4 g/cm3. Each cube was capped with a 7.6 cm concrete slab. Soil in each cube was treated with 1% chlorpyrifos (XRM-5160). The insecticide volumes used were 4.54 and 10.60 L per injection point under 50 psi. Each treatment was replicated three times. Four soil cores (each 60 cm long) were sampled from each cube at 2.4, 17.8, 33.0 and 48.3 cm below the slab. Each core was divided at equal distance into 4 subsamples. Chlorpyrifos from soil was extracted and analyzed with a gas chromatography. The residue data were analyzed using SAS Proc GLM: repeated measures, ANOVA test.

The results indicated that chlorpyrifos distribution in sandy loam soil ranged from 16 to 789 ppm at 2.4 cm depth combined with horizontal distribution up to 60 cm. Normally, >5 ppm chlorpyrifos in soil is required to control subterranean termites. Chlorpyrifos >5 ppm was not detected beyond 30 cm horizontally and 17.8 cm vertically in a loamy sand soil. In a silty clay loam, 6-1107 ppm of chlorpyrifos was detected up to 33 cm depth combined with 30 cm horizontal distance. Chlorpyrifos in sandy soil produced more horizontal distribution than the clay soil and greater vertical distribution on clay soil than sandy soil. According to these data, injection hole spaced at 30 cm during sub-slab treatment may provide a continuous chlorpyrifos barrier in soil against the subterranean termites.

MOVEMENT OF SELECTED TERMITICIDES INTO A SANDY LOAM SOIL IN THE LABORATORY

J. M. Willut, A. C. Lew, J. B. Ballard, M. J. Bonner, W. D.Gravelle and M. A. Walsh
FMC Corporation, Agricultural Chemical Group
Princeton, NJ 08543 (609)452-2300, Ext. 4565

The vertical and lateral dispersion of five termiticides into sandy loam soil was investigated following single point gravity application. The materials tested included Prevail FT (cypermethrin), Dragnet FT (permethrin), Dursban TC (chlorpyrifos), Pryfon 6 (isofenphos), and an emulsifiable concentrate formulation of bifenthrin. A micro-encapsulated formulation of chlorpyrifos, Empire, was also tested. A separatory funnel was used to slowly apply 50 ml of 250 ppm treatment solution to a point 2.5 cm below the soil surface of a box (51 x 20 x 15 cm - LxHxD) packed with soil. Four boxes were treated per compound. One day after treatment the soil in the box was sectioned horizontally into 1 cm layers. A 9 x 9 plastic grid with cells measuring 1.3 cm2 was centered over the point of application of the layers removed from the 2 to 7 cm depths. A single worker termite (*Recticulitermes flavipes* Koller) was placed in alternate cells and the grid covered with a sheet of plexiglass to contain the termites and maintain humidity. Mortality was determined 24 hours after infesting. Analysis of variance and the REGWQ test was used to compare mortality between products and layers. Formulation type had a significant impact upon termiticide dispersal into soil.

RESIDUE LEVELS OF TERMITICIDES IN SOILS TWO YEARS AFTER APPLICATION

R. B. Leidy, T. J. Sheets, and H. B. Moore
Dept. of Toxicology and Entomology
North Carolina State University, Raleigh, NC 27695-8604

A five year study was initiated in 1989 to determine the degradation rate of three termiticides which were developed to replace chlordane. Four replications of each chemical, chlorpyrifos (1.0% Dursban TC and an experimental formulation), cypermethrin (0.25%) and permethrin (0.5 and 1.0%) were established in trenches (366 by 15 by 30 cm) around existing building on three Research Stations with different soil types (sandy loam with 0.42% humic matter; clay soil with 3.59% humic matter; and clay loam with 0.46% humic matter). Soil samples were collected from each plot by taking 10, 23-cm cores, dividing them into a 0.76, 7.6-15.2, and 15.2-22.9 cm section and compositing by each depth. All soils were air dried overnight, screened (20 mesh) and 5-g samples were Soxhlet extracted and cleaned up by solid phase cartridge extractions. Samples were quantitated by GLC or HPLC. Samples have been collected two weeks, 6 months, 1 year and 2 years after application. Residues of chlorpyrifos, averaged over all depths and locations, decreased 24% (EXP) and 46% (TC) 24 months after application. Cypermethrin residues decreased 28%, and residues of permethrin decreased 25% (0.5%) and 13% (1.0%) during the same period of time. Soil type appears to effect the rate of pesticide residue degradation.

TERMITE CONTROL THROUGH PROTOZOICIDAL FOODS?

Deborah Waller
Department of Biological Science, Old Dominion University
Norfolk, VA 23529-0266

Termites are dependent on their gut fauna to digest food. Therefore disruption of the microbial community in termite hindguts represents a possible method for termite control. I examined the effect of different diets, including antibiotic and acid-treated foods, on the protozoan communities in the hindguts of the subterranean termites, *Reticulitermes* spp. (Rhinotermitidae). I also examined termite preference for these foods to determine whether they might be used as protozoicidal baits for termite control.

CUTICULAR APPLICATION VERSUS BAIT FEEDING OF SLOW-ACTING TOXICANTS FOR SUBTERRANEAN TERMITE COLONY CONTROL

Timothy G. Myles
Faculty of Forestry, University of Toronto
33 Willcocks Street, Toronto, Ontario M5S 3B3 Canada

Using cardboard roll traps in a strategically designed termite trapping system, hundreds of thousands of subterranean termites have been trapped from single colonies within a few weeks. A termite separator has been devised for rapidly removing termites from the cardboard roll traps and soil debris. The live-trapped termites can be treated with slow-acting toxicants and then released back into the colony from which they came. I refer to this as the Trap-Treat-Release (TTR) strategy. The live-trapped termites serve as ideal carriers or "vectors" of slow-acting toxicants. About 5-20% of the foraging population of a colony can be trapped and treated, and then released all at once. This should result in a more sudden and massive treatment effect on the termite colony than would be possible by the voluntary feeding of foraging termites on treated baits. Thus, the possibility of destabilizing colony homeostasis and overwhelming the colony's ability to recover seems greater than would be possible by the baiting method. Studies of serial transmission of borates applied as cuticular dusts showed that most of the transmission occurs when the untreated termites lick the cuticle of the treated termites (grooming behavior). A much smaller number of termites are subsequently affected by trophallactic transmission (exchange of gut content). By cuticular dusting with borate dusts we have obtained effective lethal ratios as high as 1 to 20 in petri dishes. The effective lethal ratio declined as dusted termites were held for longer periods of time on moist sand. Using non-toxic spray paints we were able to improve the adhesion of cuticular dust under simulated subterranean soil conditions. With groups of 2,000 untreated termites, in simulated soil gallery arenas, we obtained an average of 81% mortality with ratios of 1 treated to 20 untreated termites, and 86% mortality with ratios of 1 to 10. Intensive trapping and cuticular application appear to be two critical factors for the effective transmission of slow-acting toxicants in subterranean termite colonies. In concept, the Trap-Treat-Release strategy will use very small amounts of toxicant to rapidly suppress or kill whole colonies of termites, providing environmentally acceptable, long-term control. An important area for university-industry cooperation is in the development of a thickened, cuticular adhesive spray formulation which optimally balances properties of cuticular adhesion and grooming ingestability. Initial field trials of the Trap-Treat-Release method in urban sites in Canada are planned for 1992.

CARIBBEAN TERMITE SURVEY: II. BRITISH VIRGIN ISLANDS

Margaret S. Collins
Dept. of Entomology, Smithsonian Institution
Washington, D.C. 20560
and
Michael I. Haverty
U. S. Forest Service, USDA
Albany, CA

This report, a contribution to the surveys of the Caribbean termite fauna now in progress, describes the species found on Guana Island and some of its near neighbors of the British Virgin Island complex. Most of these islands are part of the Puerto Rico Bank, a broad plateau variously dry land or submerged during geological history, depending upon the state of glaciation. The rocks date back to the Cretaceous.

During historical times, members of the island complex have been subjected to various environmental stresses, but Guana has retained an extraordinarily diverse flora and fauna for its size (850 acres). It has been designated as a wildlife sanctuary, and is so maintained by the Jarecki family. The termite survey, sponsored by the Conservation Agency of Rhode Island, is part of the on-going effort to document the diversity persisting on Guana. Additional islands have also been screened.

Basic biological information emerging from the overall Caribbean effort can provide data pertinent to the resolution of significant problems, especially taxonomy of members of family Kalotermitidae. Descriptions and extant taxonomic keys for termites of the area are of varying utility, suffering from the use of too-small samples to permit appreciation of the range of variability inherent in the taxon. In Kalotermitidae, soldier size and relative proportions of taxonomically useful features vary greatly with age and nutritive status of the colony. In addition, many species of the kalotermitid genus Incisitermes show alternative head forms in the soldiers. It is possible that small-sample collecting in the past has led to species descriptions based on "long-headed" or "short-headed" soldier forms. Careful morphometric studies of adequate samples, associated with accurate cuticular hydrocarbon profiles can provide solutions to several problems, including accuracy of designation of endemicity.

Knowledge of the termite fauna of the Caribbean Islands can provide information on movement of pest species and threats to structures and good in near-by continental areas. The distribution of a second species of Coptotermes, C. havilandi, with habits similar to the destructive U.S. invader, C. formosanus, is of special importantce.

Impressive changes in the total number of species recorded from islands of the Caribbean since Snyder's 1956 summary are documented.

An abstract submitted for the 1992 National Conference on Urban Entomology by William H. Kern, Jr., Dept. of Entomology & Nematology, IFAS, University of Florida, Gainesville, FL 32611.

Outdoor Survival and Development of Cat Fleas in North Central Florida.

The percent survival and development times for cat fleas reared in four outdoor and two indoor situations were determined by following 1182 larvae from egg hatch to death or adult emergence. Some larvae completed development during all seasons of the year in north central Florida in sheltered microhabitats such as inside doghouses, under trees, and under trailers. No larvae survived to pupation in sunlit areas, such as open lawns. Survival was greatest in warm, humid months such as September and lowest following cold fronts in January and February. Under optimal colony conditions (85° F, 75-90% RH), cat fleas take 17 to 20 days to adult emergence. In climate controlled buildings (72° F, < 50% RH), cat fleas take 32 to 34 days to adult emergence. In sheltered outdoor situations, such as under a mobile home, development is temperature dependant. It takes an average of 21 days to adult emergence in June, 27 days in September, and 44 days in January.

Nancy C. Hinkle, Philip G. Koehler,
and R.S. Patterson

Department of Entomology & Nematology, University of Florida, and
U.S.D.A. - A.R.S., Medical & Veterinary Entomology Research
Laboratory, Gainesville, FL

Dynamics of Flea Populations on the Host

Host grooming was found to be a significant mortality factor for cat fleas as introduced populations of fleas were rapidly removed by the host and ingested. Examination of host feces allowed quantification of daily removal rates.

Male fleas were demonstrated to have shorter lifespans than female fleas, on the host. The majority of male fleas had succumbed within a week of infestation while the female flea tended to survive for upwards of two weeks.

Egg production commenced within 24 hrs of the female's first blood meal, peaked by the fourth day, and then gradually declined as the flea aged, with peak egg production just over 24 eggs per day per flea. Knowledge of the sex ratio on an animal permits population estimates based on hourly egg drop.

Other methods of determining on-host flea populations were investigated, including estimation from numbers of fleas removed with a flea comb following ten strokes, from numbers of fleas removed from continual combing until no more fleas could be removed for 50 strokes, and sequential combing until no fleas could be removed and no flea eggs were produced.

Repeated combing, like host grooming, was found to disrupt flea feeding and reduce egg production. Disparity was noted in the effect of starvation on egg production; halving of blood intake resulted in over an 80% decrease in oviposition. Temporal patterns of egg deposition were determined as were differences in egg production based on flea age.

Title: Comparison of Fenoxycarb, Methoprene and Pyriproxyfen for Outdoor Control of Cat Fleas in Four Types of Soil-Filled Containers

Authors: Champa Rajapaksha and Roger Meola
Department of Entomology
Texas A&M University
College Station, TX 77843-2475

ABSTRACT

Photostable formulations of methoprene (Altosid®), pyriproxyfen (Nylar®) and fenoxycarb (Torus®) were tested for juvenoid activity in an attempt to develop a standard procedure for screening insect growth regulators for outdoor control of cat fleas in soil. Clay, peat and plastic nursery pots and wooden plant flats filled with sandy clay loam topsoil were used to determine whether container type influenced juvenoid activity. The treated soil was protected from rainfall and exposed out-of-doors to determine the effect of ultraviolet light and fluctuating temperature on the efficacy of the juvenoids. Soil samples were assayed at 1 day and at weekly intervals after treatment by infesting the soil with flea larvae and then counting the number of fleas that developed to the adult stage.

Methoprene, fenoxycarb and pyriproxyfen were equally effective against cat fleas for 6-7 weeks in clay, peat and plastic pots at a concentration of 64.56 mg ai/m^2 (6 mg ai/ft^2)

preventing development of at least 95% of the adult fleas. However, the activity of methoprene declined significantly thereafter, compared with fenoxycarb and pyriproxyfen which continued to cause nearly 100% mortality for the entire 9 week test period. The efficacy of methoprene declined even more rapidly in wooden flats losing much of its effectiveness within 3 weeks. In contrast, the other two juvenoids at the same concentration were still 90% effective after 9 weeks. Based on these results, it was apparent that the methoprene formulation was less stable in soil than fenoxycarb and pyriproxyfen especially in wooden flats. The other containers, clay, peat and plastic nursery pots had no significant affect on juvenoid activity.

Methoprene was relatively ineffective in preventing adult emergence at levels below the 64.56 mg ai/m^2 whereas fenoxycarb and pyriproxyfen blocked 100% development at concentrations of 8.07 mg ai/m^2, 16.14 mg ai/m^2, and 32.28 mg ai/m^2. The LC_{50} values for methoprene, fenoxycarb and pyriproxyfen for cat fleas were estimated as 0.643 ppm, 0.031 ppm, and 0.028 ppm respectively when applied to soil. These values are considerably higher than LC_{50} values in sand.

SEVERE FLEA INFESTATION IN DAIRY CALVES. M.W. Dryden[1], W.E. Moore[1] and A.B. Broce[2]. Departments of Laboratory Medicine[1] and Entomology[2]. Kansas State University, Manhattan, Kansas 66506.

In June 1991 an investigation was conducted of a severe flea infestation in 23 holstein dairy calves in South Central Kansas. The flea infestation had become so severe that the owners reported the death of three calves they attributed to fleas. Inspection of the dairy revealed massive numbers of fleas on calves and in the barn they were housed. Fleas collected were identified as *Ctenocephalides felis*, cat fleas. Three lighted flea traps were used during the investigation to monitor changes in flea population levels in the environment. During the investigation 92,000 fleas were collected in these traps. Total flea recovery attempts from two calves resulted in 2,808 and 5,317 fleas being removed. Analysis of blood samples from ten calves revealed that nine of them had mild to severe anemia. A management program was recommended consisting of treatment of calves (permethrin - methoprene) and premises (chlorpyriphos - methoprene), removal of straw bedding from barn and reduction of stray cat population. Inspection of dairy nine weeks after control program was instituted revealed that fleas were not evident on calves or in the premises.

Evaluation of Methoprene, Pyriproxyfen and Microencapsulated Chlorpyrifos for Outdoor Control of Cat Fleas, Ctenocephalides felis

Kathleen G. Palma and Roger W. Meola
Department of Entomology
Texas A&M University
College Station, TX 77843-2475

Three compounds, methoprene, pyriproxyfen and microencapsulated chlorpyrifos were used to treat home yards for control of cat fleas. Pretreatment samples were taken from the study yards to determine if there was an existing flea population. Areas suspected as flea habitats were measured and marked for treatment. The methoprene evaluation however focused on the entire yard so "hot spots" were not considered.

Once the yards were treated, weekly soil samples were collected and returned to the laboratory for bioassay using late second and early third instar larvae. Weekly homeowner interviews were conducted when possible. Weekly inspections of the pet were also done.

Methoprene applied at a rate of 6 mg AI (active ingredient)/ft^2 inhibited adult cat flea emergence by less than 50% for the first two weeks. After two weeks, there was no significant difference between the treated or nontreated yards. In this field study, methoprene did not exhibit long lasting residual activity. This could be attributed to its lack of photostability.

Pyriproxyfen (Nylar®) at a rate of 6 mg AI/ft^2 and microencapsulated chlorpyrifos (Empire 20®) at a labelled rate of 0.4% spray (10 gal H_2O/1000 ft^2) were applied in two different localities, Bryan/College Station and Corpus Christi, Texas.

The Nylar® treated yards in Corpus Christi had less than 50% adult flea emergence for the first three weeks while the Bryan/College Station yards showed less than 50% adult emergence for the first four weeks.

The Empire 20® treated yards in Corpus Christi had less than 50% adult emergence for the first six weeks while the Bryan/College Station yards had less than 5% adult emergence for the first 5 weeks and less than 50% adult emergence for the first 10 weeks.

Corpus Christi, Texas received approximately 1.5 times more rainfall during the treatment and sampling periods than Bryan/College Station. By using different geographical locations for test sites, rainfall was identified as a potential limiting factor when considering residual activity of pyriproxyfen (Nylar®) and microencapsulated chlorpyrifos (Empire 20®).

EVALUATION OF DEET AS A TICK REPELLENT

Phyllis G. Weintraub, Marvin L. Bertsch, Niketas C. Spero, Robin G. Todd

Insect Control and Research, Inc.

Abstract

The efficacy of various concentrations of DEET (10, 30, 40, 50, 60, 70, 80, and 100%) as a tick repellent was tested. Usually five participants (one control and four others, each treated with one concentration of DEET per test day) pulled DEET treated 2 X 3 foot cotton flannel drags through seven areas of a watershed forest. Each concentration of DEET was repeated on three separate days.

Ticks were removed from overalls with masking-tape lint rollers and counted in the laboratory under a dissecting microscope. Ticks on the drags were killed by freezing then counted. Approximately 30,000 ticks, almost all were *Ixodes dammini* and predominantly in the larval stage, were removed during the course of the study.

There was a noticeable drop in the numbers of ticks collected after the first day, possibly indicating that physical removal can influence tick populations or that the larval population had peaked (maximum number of eggs hatched). However, there were sufficient numbers of ticks to obtain discrimination between the high concentrations of DEET during all collection dates.

All concentrations of DEET afforded some level of protection; however, concentrations of 60% and greater had significantly fewer ticks, offered the highest level of protection (98.1% to 98.7%) and showed no clear evidence of breaking down over time. No concentration of DEET consistently provided complete protection from ticks.

THE EFFECT OF ELECTRICAL CURRENT ON THE BEHAVIOR OF THE WORKER CASTE OF THE ANT *MONOMORIUM PHARAONIS*

by Dr. Jerrold R. Harris
Center for Urban and Public Health Entomology
Texas A&M University

A number of ant species have been reported to be attracted to electrical fields, some of which can be serious pests when they occur in or near structures containing electrical circuits. Perhaps the best known of these ant species is *Solenopsis invicta*. This ant is known to damage electrical circuits. However, pest control operators have noted that ants of the species *Monomorium pharaonis* (Pharaoh ant) concentrate around the electrical outlets in homes as well. A series of investigations using regular double-stranded household electrical wiring as the test material was performed with workers of this species to investigate the influence of electrical fields on these ants.

Results from the series of tests indicate that the behavior of the workers is influenced by the presence of the electrical current. This influence is also affected by the location of the wiring in relation to surrounding surfaces and the ants themselves as well as by the amount of insulation surrounding the wiring. However, the behavior demonstrated by the worker ants is described as an arresting of the foraging behavior and not a true attraction to the electrical fields.

When the influence of bare electrical wiring was compared to that of insulated wiring, it was found that there was an increase in the number of ants arrested around the bare wiring with the electrical current turned on. This reaction seems to indicate that the ants were perceiving the presence of the current and influenced by this presence.

The distance at which the two strands of the electrical wiring were spread apart also influenced the arrestment behavior. When the number of ants found surrounding wires with strands spread to distances of 1, 5, and 10mm were compared, it was found the number of ants surrounding these wires again increased with the current turned on. However, the number of ants arrested at the wires decreased with the enlargement of the distances between the wire strands.

Further tests demonstrated that the workers ants could perceive the presence of the electrical current from no more than approximately 5mm distant. At larger distances, the ants were not significantly influenced by the presence of the wire whether bare or insulated.

The means by which *M. pharaonis* workers are influenced by electrical fields remains uncertain. However, the influencing factors seem to arrest the movement of the foraging ants when they come within about 5mm from the electrical source. The influence does not seem to be an attraction to the electrical field because the ants are not "pulled" into the field and remain. When the ants are within the influencing area of the field, they remain for a short time and continue to forage.

As of this time, the affect of magnetism and heat are ruled out as possible factors which the ants are perceiving when within the electrical field. Test indicate that there were no significant increases in the temperature of the electrical wiring used in the experiments when the current was turned on. Magnetism was ruled out because the presence of electrical insulation decreased the number of worker ants influenced by the current. Lines of magnetism are transmitted through insulation and if this were the influencing factor, the number of ants arrested by the current would not be different between the two types of wiring.

While the arrestment of foraging had been noted in *M. pharaonis* as well as other species of ant, little is known about what factors are involved in this behavior. However, some of important factors in this behavior seem to be the distance the ants are from the source of the electrical field and the amount of insulation around the wiring.

Field Performance of The Entomopathogenic Fungus *Metarhizium anisopliae* in Enclosed Inoculation Chambers for German Cockroach (*Blattella germanica*) Control

Jeffrey B. Tucker[1], Jeff Cook[2], Debra Fenton[3], Michael Andis[4]

Consumer demand for increasingly safe and naturally derived insecticides has pressured the urban structural pest management industry to develop alternatives to traditional band and spot applications of organic chemicals. The development of containerized cockroach baits in convenient packaging has revolutionized the over-the-counter insecticide industry.

The most recent development in pre-packaged cockroach baits is the incorporation of entomopathogenic fungi in "inoculation chambers" which include a non-toxic bait simply as a means of bringing cockroaches in contact with fungal spores to achieve control.

A field study was conducted to evaluate an enclosed, baited inoculation chamber containing *M. anisopliae* (EcoScience Laboratories) for German cockroach (*Blattella germanica*) control. Trial sites were forty low-income single family residences in Houston, Texas. Units were assigned one of four treatment protocols based on a randomized block design. Ten units were treated with a single placement of twelve *M. anisopliae* inoculation chambers (12 ESL) each. Ten units were treated with a single placement of twenty-four inoculation chambers (24 ESL) and ten units were treated with twelve inoculation chambers which were all replaced four weeks after initial treatment (12 + 12 ESL). A standard for comparison was provided by treating ten units with twelve MaxForce Roach Control System (American Cyanamid) bait stations.

The degree of pre-treatment infestation of German cockroaches was estimated by sticky trap catch counts in each unit's kitchen. Trap catch counts were performed at 2, 4, 6 and 8 weeks post-treatment and percent reductions in catch counts were calculated. The 24 ESL treatment protocol with *M. anisopliae* inoculation chambers and the MaxForce bait station treatment protocol achieved similar percent reductions in trap catch counts although there is greater variability in the MaxForce results. The 12 ESL and the 12 + 12 ESL protocols provided generally lower percent reductions and greater variability in results.

The efficacy demonstrated by the *M. anisopliae* inoculation chambers in these challenging conditions indicates that this product may be integrated into urban pest management strategies.

[1]Entomology Associates, P.O. Box 70375, Houston, Texas 77270
[2]University of Texas, School of Public Health, Houston, Texas
[3]EcoScience Laboratories, Inc., Amherst, Massachusetts
[4]Roussel-Bio Corporation, Lincoln Park, New Jersey

The effects of interspecific competition on oviposition behavior in two species of cockroaches, *Periplaneta fuliginosa* and *Periplaneta americana*.

J. M. Gordon and P. A. Zungoli
Department of Entomology, Clemson University
Clemson, S.C. 29634-0365

In the Southeastern United States, two species of cockroaches in the genus *Periplaneta* are commonly found together, the smokybrown cockroach, *P. fuliginosa* and the American cockroach, *P. americana*. Although their habitats are not identical, they are generally found as indoor/outdoor pests of homes surrounded by old hardwood trees and vegetation. Both cockroaches reproduce by depositing a hardened ootheca in a substrate. The oothecae hatch in 30-40 days yielding an average of 16-18 nymphs for American cockroaches and 20-22 nymphs for smokybrown cockroaches.

The objective of this study was to examine the effects of one species on another s oviposition behavior. The experiment was conducted by placing ten newly molted and newly inseminated female cockroaches into glass aquaria which contained four substrate choices for oviposition. The substrates were a wooden wall void structure, peat moss, marble chips and bare glass. Three tanks contained only smokybrown cockroaches, three tanks contained only American cockroaches and three tanks contained five each American and smokybrown cockroaches. Only females were placed in the aquaria. The cockroaches were kept undisturbed in the aquaria for seven weeks, after which time, they were removed. Oothecae were recorded with respect to their location and species and then on hatching, number of nymphs were recorded. Damaged oothecae were recorded separately.

Overall, peat was the substrate used most frequently by both American and smokybrown cockroaches in either pure or mixed colonies. American cockroaches used the peat almost exclusively in pure colonies and in mixed colonies used the marble chips occasionally. However, they never used the vertical wall void surface in which to deposit their oothecae. Smokybrown cockroaches oviposited in the wall void about 15% of the time in pure colonies and >30% of the time in mixed colonies and rarely used the marble chips. Bare glass was almost never chosen by either species as an oviposition site. Interestingly, American cockroaches damage their own oothecae by chewing on them in pure colonies and smokybrown cockroaches do not. However in mixed colonies, the majority of damaged oothecae were smokybrown cockroach oothecae. This may indicate that American cockroaches were selectively cannibalizing smokybrown oothecae in mixed colonies as a result of competition but such conclusions would need observational data to be substantiated. Finally, the average number of oothecae produced by smokybrown and American cockroaches in pure colonies was 77, in mixed colonies the average number of oothecae was significantly less at 61. This number was lower because of lower numbers of smokybrown oothecae.

Analysis of German cockroach foraging efficiency in the laboratory using non-stationary Markov Chains

Joe J. DeMark[1]
Tom Kuczek[2]
Gary W. Bennett[1]

Abstract

Computerized moving image analysis (MIA) was utilized in the laboratory to track the movement behavior of both second and fifth instar German cockroaches between food, water and harborage sites for the entire instar duration within an enclosed arena. It appeared that the cockroaches were becoming more efficient (less random) in their movements between the resource sites as the time spent in the laboratory arena increased. Therefore, a non-stationary Markov Chain statistical analysis was performed on the movement data to determine transition rates between the resource sites every 12 hours (12:12, L:D cycle). An examination of the transition rates showed that the fifth instars became more efficient over time in their movements between the resource sites in both the light and dark cycles. The second instars did not become more efficient over time. These findings support those of Cloarec and Rivault, 1991 who have shown in the field that German cockroaches improve their foraging performance as they grow larger. Graphs of transition rates for various days and cummulative trace diagrams of various days will be presented to support these findings.

[1] Center for Urban and Industrial pest Management, Department of Entomology, Purdue University, West Lafayette, IN 47907.

[2] Department of Statistics, Purdue University, West Lafayette, IN 47907.

Cockroach allergens in urban environments are a major risk factor for acute asthma attacks.

Martin D. Chapman, Lisa D. Vailes, Donald E. Mullins,
Susan M. Squillace, Lawrence E. Gelber and Thomas A.E. Platts-Mills.

Division of Allergy and Clinical Immunology,
University of Virginia, Charlottesville, VA

Cockroach (CR) allergens have been known to cause immediate allergic reactions for over 20 years and have been associated with asthma symptoms in urban areas, such as Chicago, Washington DC, New York and New Orleans. The principal species involved are *Blattella germanica* and *Periplaneta americana*. In recent studies, we raised a panel of monoclonal antibodies to *B. germanica* which defined two protein allergens, *Bla g* I and *Bla g* II, and developed enzyme immunoasays (ELISA) for measuring these allergens in house dust samples (see Pollart *et al*, J Allergy Clin Immunol 87:511-521, 1991). Approximately 40% and 80% of CR allergic patients make IgE antibodies to *Bla g* I and *Bla g* II, respectively.

To investigate the role of CR allergens as risk factors for acute asthma attacks, we have compared the prevalence of IgE antibodies to CR in patients presenting to hospital Emergency Rooms (ER) with asthma, with that of age and sex matched controls presenting to the ER with other diagnoses. These studies were carried out in Charlottesville, VA, Altanta, GA and Wilmington, DE and involved comparisons of antibody levels to CR and other environmental allergens (dust mite, cat, ragweed and ryegrass pollen) in over 200 patients with asthma and an equal number of controls. The results show that 38% of asthmatics, as compared to 8% of controls, had IgE antibody to the 3 indoor allergens (mite cat and CR), and that in the Wilmington study 25/114 asthmatics as compared to 7/114 controls had IgE antibody to CR. There were also significant racial differences in allergen exposure: most CR allergic patients were black, whereas most cat allergic patients were white ($p<0.001$).

Environmental exposure to CR allergens (*Bla g* I and *Bla g II*) was compared by analysing allergen levels in 4 dust samples (kitchen, bedding, bedroom floor and sofa) from 186 houses (93 asthma patients and 93 controls) from Wilmington. Most patients admitted to the ER with asthma who had serum IgE antibodies to CR had dust samples which contained >2units *Bla g* II per gram dust in their homes (range 2-500 units/g). Allergen levels in kitchen dust were higher than in dust samples from the other sampling sites and, interestingly, ~20% of homes without visible evidence of CR infestation had detectable CR allergen in dust samples.

Estimates of population attributable risk suggest that admission to the ER with asthma was associated with IgE antibody to indoor allergens in 40-56% of cases. The increase in asthma mortality and morbidity in the US has occurred primarily among black populations living in urban areas. Our results suggest that senstization and exposure to CR allergens is an imoportant risk factor for asthma attacks among these populations and that methods of reducing CR infestation should be considered as part of the management of the disease.

Insecticide Resistance Detection for the German Cockroach (Dictyoptera: Blatellidae) with Glue-Toxin Traps.

J. I. MOSS, R. S. PATTERSON, AND P. G. KOEHLER[1]

USDA - ARS, Medical & Veterinary Entomology Research Laboratory, P.O. Box 14565, 1600 S.W. 23rd Dr., Gainesville, Florida, 32604

1/ Department of Entomology and Nematology, University of Florida, Gainesville, Fl. 32611.

ABSTRACT

We have developed a way to check for insecticide resistance in German cockroaches, Blatella germanica (L.), at the site of infestation. Insecticide impregnated glue was evaluated for its ability to yield useful toxicological data for German cockroaches. Toxicities of three classes of insecticides (carbamate, organophosphate, and pyrethroid) were evaluated using topical applications and exposure to insecticide impregnated glue. Cockroaches which were resistant to topical insecticide applications were also resistant to the glue formulation. Reliability of results was greatest when mortality was scored 40 to 48 h after the cockroaches become stuck on the glue.

Field test using diagnostic doses based on probit analysis have been conducted. Insecticide treated traps were left in an infested area over-night and removed the next day. The traps were examined for live cockroaches the afternoon of day following removal of the trap. Preliminary tests using multiples of the LC_{99} and LC_{90} resulted in underestimates of mortality in treated apartments. We have gotten improved predictability using 10 times the LC_{50} as a diagnostic dose. In addition to bendiocarb, cypermethrin, and dursban, we have added malathion, propoxur and sevin to our field tests.

MONITORING OF COCKROACH POPULATIONS IN PUBLIC HOUSING AS PART OF INTEGRATED PEST MANAGEMENT STRATEGY OF CONTROL

Sam Bryks, M.Sc. R.P.E. Manager, Pest Control Programs

Metropolitan Toronto Housing Authority
Toronto, Ontario, Canada

A program of monitoring for cockroach populations within individual apartments of entire buildings was developed. Two glue traps for trapping German cockroach Blatella germanica are placed at selected location sites. Traps are checked 48 hours later. A number of treatment protocols are recommended for individual apartments on the basis of the population sample determined from monitoring. Results from more than 40 buildings showed that in most cases 70% of apartments did not have detectable infestation or had low detectable infestations (less than 10 insects on two monitors). Only 10 - 20% of suites required full insecticidal treatment. All others were treated by cockroach bait stations alone. Considerable variations in distribution of degree of infestation can exist between different buildings. Such variations highlight the inefficiency of non-targetted total building treatments. Selected treatment protocols on the basis of pretreatment levels of infestation enable remarkable reduction of insecticide use and inconvenience to residents. This paper emphasizes the value of pretreatment monitoring as a tool for selection of treatment protocols as well as of post-treatment monitoring for evaluation of success of control. The validation of population sampling by glue traps as a means of establishing action threshold levels in the urban setting is discussed.

Identification and environmental distribution of whole body and aerosolized allergens from German and American cockroaches

R. J. Brenner, R. M. Helm, A. W. Burks & L. W. Williams

USDA-ARS-MAVERL, Gainesville, FL, and Arkansas Children's Hospital, Little Rock, AR

Cockroaches produce a plethora of allergenic proteins. Clinical studies indicate that persons with allergies to German cockroaches may react to 8-13 proteins; which protein elicits an allergenic response appears to be a function of (1) genetic predisposition, (2) history of exposure to cockroaches, and (3) mechanism of exposure (dermal, inhalant, ingested). This research identified the principal allergenic proteins in American and German cockroach whole body preparations, and also characterized the aeroallergens from cockroach colonies. Data indicate that aerosolized allergens are of only three sizes, 36 kiloDaltons (kD), 55 kD and 80 kD, whereas whole body extracts produce a greater range of allergenic proteins. Surface allergens were mapped following release of German cockroaches into test kitchens, and airborne levels were measured periodically. Data revealed a high concentration of surface allergens in the areas of food preparation and storage.

"Influence of surface type on residual activity of several commercial insecticides" Jeff M. Edwards and Laura L. Karr , DowElanco Insecticide Discovery Group, Walnut Creek, CA

Two experiments to evaluate the effect of surface type on the performance of one experimental and several commercial insecticide formulations were conducted. The initial and residual activity of three pyrethroids against German cockroaches was assessed on oily and oil-free masonite. Masonite panels were pretreated with corn oil or left oil-free and were then sprayed with wettable powder formulations of esfenvalerate, DEMON, and TEMPO. Adult male German cockroaches were caged upon the treated panels at various post-treatment intervals. Corn oil pretreatment was found to adversely affect the residual activity of all three materials. Next, the initial and residual activities of EMPIRE, FICAM+, and DEMON on oily and oil-free masonite and stainless steel were evaluated. Caging adult male German cockroaches upon treated panels at various post-treatment intervals revealed that the three insecticides interacted uniquely with the four surface types; overall, however, corn-oil pretreatment adversely affected residual activity of all materials studied on both surfaces. The impact of surface interactions on insecticide performance and evaluation in the lab and in the field will be discussed.

Wednesday, February 26

AUDITORIUM

Eric Benson, Moderator

8:30 am RECENT DEVELOPMENTS IN CHEMICAL COMMUNICATION
Coby Schal, Rutgers

9:15 am COMMUNICABLE DISEASES AND VECTOR CONTROL - AN UPDATE
Jim Olsen, Texas A & M

10:00 am URBAN PEST MANAGEMENT IN THE 1990S
David Naffziger, Whitmire

10:45 am CLOSING REMARKS
Gary Bennett, Conference Chair

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Judy Bertholf	Bill Robinson
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NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

February 23-26, 1992

University of Maryland
Adult Education Center
College Park, Maryland

Sunday, February 23

7:30 - 8:30 pm REGISTRATION
Lobby Conference Center

8:00 - 10:00 pm MIXER (WITH CASH BAR)
Chesapeake Room

Monday, February 24

8:00 am **REGISTRATION** – *Lobby — Conference Center*

AUDITORIUM

8:30 am INTRODUCTION AND WELCOME
Gary Bennett, Conference Chair

9:00 am ***Arnold Mallis Memorial Lecture***
TERMITOLOGY - A CAREER PERSPECTIVE
Frances Weesner Lechleitner, Colorado State

9:45 am COCKROACH RESISTANCE MANAGEMENT - ROTATION?
Bill Plapp, Texas A & M

10:30 am **COFFEE BREAK** – *Lobby*

11:00 am EXPERT SYSTEMS AND DECISION MAKING FOR URBAN IPM
Nick Stone, VPI & SU

11:30 am PUBLIC PERCEPTION - URBAN IPM
Harvey Gold, NPCA

12:00 noon **LUNCHEON** – *Chesapeake Room*

1:30 pm CONCURRENT PAPER SESSIONS

TERMITES .... Room 1105
Moderators: Mike Chambers and Jim Smith

COCKROACHES .... Room 1123
Moderators: Brian Schneider and Pat Zungoli

FLEAS, ANTS AND OTHER URBAN PESTS .... Room 1109
Moderators: Mike Dryden and Phil Koehler

2:50 pm **COFFEE BREAK** – *Lobby*

3:30 pm CONCURRENT DISCUSSION SESSIONS

TERMITES .... Room 1105
Moderators: Jim Smith and Mike Chambers

COCKROACHES .... Room 1123
Moderators: Pat Zungoli and Brian Schneider

FLEAS, ANTS AND OTHER URBAN PESTS .... Room 1109
Moderators: Phil Koehler and Mike Dryden

5:00 pm **ADJOURN**

Tuesday, February 25

AUDITORIUM
Judy Bertholf, Moderator

8:30 am RESEARCH DIRECTIONS - IMPACT OF THE PUBLIC AND POLITICS
Ron Sbragia, DowElanco

9:15 am CARPENTER ANT BEHAVIOR-IMPLICATIONS FOR PEST MANAGEMENT
John Klotz, Purdue

10:00 am **COFFEE BREAK** – *Lobby*

10:30 am SAMPLING GERMAN COCKROACH FIELD POPULATIONS: THEORY, RELIABILITY AND ANALYSIS
Byron Reid, Purdue and **Art Appel**, Auburn

12:00 noon **LUNCHEON** – *Chesapeake Room*

12:30 pm POSTER SESSION – *Lobby*
George Rambo, Moderator

AUDITORIUM
Bill Robinson, Moderator

1:30 pm SOIL SAMPLING - ISSUES AND DIRECTIONS
Lonnie Matthews, ASPCRO

2:15 pm TERMITE DISTRIBUTION, COLONY SIZE AND POTENTIAL FOR DAMAGE
Ken Grace, University of Hawaii

3:00 pm **COFFEE BREAK AND POSTER SESSION** – *Lobby*

3:30 pm BAITS AND BAITING TECHNOLOGY
Don Reierson, University of California-Riverside

4:15 pm RECENT ADVANCES IN TERMITE BIOLOGY AND CONTROL
Nan Yao Su, University of Florida

6:00 pm **RECEPTION & CASH BAR** – *Chesapeake Room*

7:00 pm **BANQUET**
Master of Ceremonies: **Roger Gold**
Speaker: **Tom Turpin**, President ESA

POSTER PRESENTATIONS

(Lobby)

Tuesday Afternoon – February 25, 1992

12:30 - 1:30 pm & 3:00 - 3:30 pm

Moderator: George Rambo

THE INFLUENCE OF SOIL PH UPON TERMITICIDE DEGRADATION
J.B. Ballard and **J.R. Schussler**, FMC Corporation, Princeton, NJ; **R.C. DeWitt**, Ricera, Inc., Painesville, OH

SCANNING ELECTRON MICROSCOPY OF THE EASTERN AND FORMOSAN SUBTERRANEAN TERMITE
F.M. Oi, Dept. of Entomology and Nematology, University of Florida, Gainesville, FL

ENTRAPMENT/ENCAPSULATION OF BAIT PESTICIDE FORMULATIONS WITHIN CULIGEL[T] SUPERABSORBENT POLYMER MATRICES: COCKROACH CONTROL STUDIES
R. Levy, M.A. Nichols, and **T.W. Miller, Jr.**, Lee County Mosquito Control District, Ft. Myers, FL

BIOLOGICAL OPTIMIZATION OF MICROENCAPSULATED DIAZINON FOR USE AGAINST *BLATTELLA GERMANICA* (L)
Eric W. Moyses and **R. Schenker**, Ciba-Geigy Ltd., Basle, Switzerland

MOLT INHIBITION IN GERMAN COCKROACHES (DICTYOPTERA: BLATTELLIDAE) CAUSED BY THE CHITIN SYNTHESIS INHIBITOR FLUFENOXURON: AN SEM PERSPECTIVE
D.R. Suiter and **P.G. Koehler**, Dept. of Entomology and Nematology; **R.S. Patterson**, ARS-MAVERL, University of Florida, Gainesville, FL

DEVELOPMENT OF *BEAUVERIA BRASSICA* AS A MICROBIAL CONTROL FOR FIRE ANTS
Jerry L. Stimac, R.M. Pereira, and **D.H. Oi**, Dept. of Entomology and Nematology, University of Florida, Gainesville, FL

COMPUTERIZED URBAN PEST MANAGEMENT TRAINING
Thomas R. Fasulo and **P.G. Koehler**, Dept. of Entomology and Nematology, University of Florida, Gainesville, FL

NEMATODE BASED BIOLOGICAL CONTROL OF GERMAN COCKROACHES
Stephen Manweiler and **T. Weber**, Biosys, Palo Alto, CA

PENETRATION OF SOUTHERN PINE FLOOR JOISTS BY BORATE/GLYCOL FORMULATIONS
Maureen E. Puettmann and **L.H. Williams**, USDA Forest Products Research Lab, Gulfport, MS

THE BUILDING AS AN URBAN LIVING PLACE FOR SYNANTHROPIC ORGANISMS
Ingrid Korber, Killgerm GmbH, Berlin, Germany

PRESENTED PAPERS

Monday Afternoon – February 24, 1992

1:30 - 2:50 pm	Concurrent Submitted Paper Sessions
2:50 - 3:30 pm	Coffee
3:30 - 5:00 pm	Concurrent Discussions Sessions *(All authors and moderators)*

FLEAS, ANTS AND OTHER URBAN PESTS

Moderators: Mike Dryden and Phil Koehler

Room 1109

1:30 - 1:40 pm OUTDOOR SURVIVAL AND DEVELOPMENT OF CAT FLEAS IN NORTH CENTRAL FLORIDA
William H. Kern, Jr., Dept. of Entomology and Nematology, University of Florida, Gainesville, FL

1:40 - 1:50 pm DYNAMICS OF FLEA POPULATIONS ON THE HOST
Nancy C. Hinkle and **Philip G. Koehler**, Dept. of Entomology and Nematology; **R.S. Patterson**, USDA-ARS, University of Florida, Gainesville, FL

1:50 - 2:00 pm COMPARISON OF FENOXYCARB, METHOPRENE AND PYRIPROXYFEN FOR OUTDOOR CONTROL OF CAT FLEAS IN FOUR TYPES OF SOIL-FILLED CONTAINERS
Champa Rajapaksha and **Roger Meola**, Dept. of Entomology, Texas A & M University, College Station, TX

2:00 - 2:10 pm EVALUATION OF METHOPRENE, PYRIPROXYFEN AND MICROENCAPSULATED CHLORPYRIFOS FOR OUTDOOR CONTROL OF CAT FLEAS, *CTENOCEPHALIDES FELIS*
Kathleen G. Palma and **Roger W. Meola**, Dept. of Entomology, Texas A & M University, College Station, TX

2:10 - 2:20 pm SEVERE FLEA INFESTATION IN DAIRY CALVES
M.W. Dryden and **W.E. Moore**, Dept. of Laboratory Medicine; **A.B. Broce**, Dept. of Entomology, Kansas State University, Manhattan, KS

2:20 - 2:30 pm EVALUATION OF DEET AS A TICK REPELLENT
Phyllis G. Weintraub, Marvin L. Bertsch, Niketas C. Spero, and **Robin G. Todd**, Insect Control and Research, Inc., Baltimore, MD

2:30 - 2:40 pm SITE SPECIFIC PERIMETER CONTROL OF PEST ANTS: SOME CONSIDERATIONS
Awinash P. Bhatkar, Initiative for Urban Social Insects Research, College Station, TX

2:40 - 2:50 pm THE EFFECT OF ELECTRICAL CURRENT ON THE BEHAVIOR OF THE WORKER CASTE OF THE ANT *MONOMORIUM PHARAONIS*
Jerrold R. Harris, Center for Urban and Public Health Entomology, Texas A & M University, College Station, TX

Cockroaches

Moderators: Brian Schneider and Pat Zungoli

Room 1123

1:30 - 1:40 pm Identification and Environmental Distribution of Whole Body and Aerosolized Allergens from German and American Cockroaches
R.J. Brenner, USDA-ARS-MARVERL, Gainesville, FL; **R.M. Helm**, **A.W. Burks**, and **L.W. Williams**, Arkansas Children's Hospital, Little Rock, AR

1:40 - 1:50 pm Cockroach Allergens in Urban Environments are a Major Risk Factor for Acute Asthma Attacks
Martin D. Chapman, **Lisa D. Vailes**, **Donald E. Mullins**, **Susan M. Squillace**, **Lawrence E. Gelber**, and **Thomas A.E. Platts-Mills**, Division of Allergy and Clinical Immunology, University of Virginia, Charlottesville, VA

1:50 - 2:00 pm Analysis of German Cockroach Foraging Efficiency in the Laboratory Using Non-stationary Markov Chains
Joe J. DeMark and **Gary W. Bennett**, Center for Urban and Industrial Pest Management, Dept. of Entomology; **Tom Kuczek**, Dept. of Statistics, Purdue University, West Lafayette, IN

2:00 - 2:10 pm The Effects of Interspecific Competition on Oviposition Behavior in Two Species of Cockroaches, *Periplaneta fuliginosa* and *Periplaneta americana*
J.M. Gordon and **P.A. Zungoli**, Dept. of Entomology, Clemson University, Clemson, SC

2:10 - 2:20 pm Monitoring of Cockroach Populations in Public Housing as Part of Integrated Pest Management Strategy of Control
Sam Bryks, Pest Control Programs, Metropolitan Toronto Housing Authority, Toronto, Ontario, Canada

2:20 - 2:30 pm Influence of Surface Type on Residual Activity of Several Commercial Insecticides
Jeff M. Edwards and **Laura L. Karr**, DowElanco Insecticide Discovery Group, Walnut Creek, CA

2:30 - 2:40 pm Field Performance of the Entomopathogenic Fungus *Metarhizium anisopliae* in Enclosed Inoculation Chambers for German Cockroach (*Blattella germanica*) Control
Jeffrey B. Tucker, Entomology Associates, Houston, TX; **Jeff Cook**, University of Texas, School of Public Health, Houston, TX; **Debra Fenton**, EcoScience Laboratories, Inc., Amherst, MA; **Michael Andis**, Roussel-Bio Corporation, Lincoln Park, NJ

2:40 - 2:50 pm Insecticide Resistance Detection for the German Cockroach (Dictyoptera: Blattellidae) with Glue-Toxin Traps
J.I. Moss and **R.S. Patterson**, USDA-ARS, Medical and Veterinary Entomology Research Laboratory; **P.G. Koehler**, Dept. of Entomology and Nematology, University of Florida, Gainesville, FL

Termites

Moderators: Mike Chambers and Jim Smith

Room 1105

1:30 - 1:40 pm The Effects of Temperature and Humidity on Survival and Feeding Rates in the Western Drywood Termite, *Incisitermes minor*
B.J. Cabrera and **M.K. Rust**, Dept. of Entomology, University of California-Riverside

1:40 - 1:50 pm Formosan Termite Swarming Behavior
G. Henderson, Dept. of Entomology, Louisiana State University, Baton Rouge, LA

1:50 - 2:00 pm Distribution of Sub-Slab Injected XRM-5160 in Soil
S.T. Kamble and **R.W. Davis**, Environmental Programs, University of Nebraska, Lincoln, NE; **M.P. Tolley**, DowElanco, Indianapolis, IN

2:00 - 2:10 pm Movement of Selected Termiticides into a Sandy Loam Soil in the Laboratory
J.M. Willut, **A.C. Lew**, **J.P. Ballard**, **M.J. Bonner**, **W.D. Gravelle**, **M.A. Walsh**, FMC Corporation, Princeton, NJ

2:10 - 2:20 pm Residue Levels of Termiticides in Soils Two Years After Application
R.B. Leidy and **T.J. Sheets**, Dept. of Toxicology; **H.B. Moore**, Dept. of Entomology, North Carolina State University, Raleigh, NC

2:20 - 2:30 pm Termite Control through Protozoicidal Foods?
D.A. Waller, Dept. of Biological Sciences, Old Dominion University, Norfolk, VA

2:30 - 2:40 pm Cuticular Application Versus Bait Feeding of Slow-acting Toxicants for Subterranean Termite Colony Control
T.G. Myles, Faculty of Forestry, University of Toronto, Ontario, Canada

2:40 - 2:50 pm Caribbean Termite Survey: II. British Virgin Islands
M.S. Collins, Smithsonian Institute, Washington, DC and **M.I. Haverty**, USDA-Forest Service, Berkeley, CA

List of Registrants

WESTERN EXTERMINATOR CO.
1732 Kaiser Ave.
Irvine, CA 92714

Andy Adams
ROUSSEL UCLAF ENV. HEALTH
Mcintyre House
High Street
Berkhamsted, Herts, H4 2DY
England

Jay Adcock
GRIFFIN CORP
P.O. Box 1847
Valdosta, GA 31603-1847

Roger Akre
DEPT. OF ENTOMOLOGY
Washington State University
Pullman, WA 99164-6382

Sandra Alvey
US ENV HYGIENE AGENCY
Attn: Entomological Sciences Division
Aberdeen Proving Ground, MD 21010-5422

Chip Anderson
MILES, INC.
1587 Phoenix Blvd. #6
College Park, GA 30349

Michael Andis
ROUSSEL BIO CORP
170 Beaverbrook Road
Lincoln Park, NJ 07035-1495

Arthur Appel
DEPT. OF ENTOMOLOGY
Auburn University
301 Funchess Hall
Auburn, AL 36849-5413

William Arrison
ROUSSEL BIO CORP
170 Beaverbrook Road
Lincoln Park, NJ 07035-1495

Charles M. Bair
U.S. BORAX CHEMICAL CO.
3075 Wilshire Blvd.
Los Angeles, CA 90010

Larry Baker
DEPT. OF HEALTH
Room 705, Hannibal House
Elephant & Castle
London, SE16TE
England

Terry Baker
AMERICAN CYANAMID CO.
Ag Division
One Cyanamid Plaza
Wayne, NJ 07470

John Balfour
HEALTH DEPT.
P.O. 67 Dubai Municipality
Dubai,
United Arab Emirates

James Ballard
FMC CORP.
P.O. Box 8
Princeton, NJ 08543

Nonsgang Bao
DEPT. OF ENTOMOLOGY
Urban Pest Control Research Center
Virginia Tech
Blacksburg, VA 24061-0319

John Barcay
ECOLAB INC
840 Sibley Memorial Hwy.
Mendota Heights, MN 55118

Joe Barile
610 Ware St.
Mansfield, MA 02048

Bob Barlow
DEPT. OF ENTOMOLOGY
Urban Pest Control Research Center
Virginia Tech
Blacksburg, VA 24061-0319

C.W. Bartholomai
3148 Leivox Road, N.E.
Atlanta, GA 30324-2818

Sharon Bartku
COMMANDING OFFICER
Box 10068
Code 16 A S.B., Applied Bio.
Charleston, SC 29411-0068

Raymond Beal
17 Alava Lane
Hot Springs Village, AR 71909

Gary Bennett
DEPT. OF ENTOMOLOGY
Purdue University
West Lafayette, IN 47907

Eric Benson
AUBURN UNIVERSITY
206 Extension Hall
Auburn, AL 36894-5629

Jonathan Berger
WHITMIRE RESEARCH LABS
3568 Tree Court Ind. Blvd.
St. Louis, MO 63122

Richard Berman
WALTHAM CHEMICAL CO.
817 Moody St. Box 538
Waltham, MA 02254

Bob Berns
PEST CONTROL TECHNOLOGY
1500 Sheridan Road
Apt. 8 H
Wilmewet, IL 60091

Judy Bertholf
DOWELANCO
13355 Noel Road
Suite 1045
Dallas, TX 75240-6604

Marvin Bertsch
INSECT CONTROL & RESEARCH
1330 Dillon Heights Ave.
Baltimore, MD 21228-1199

Donald Bieman
16218 S W 75th Street
Archer, FL 32618

B.J. Bilas
NOR-AM
3509 Silverside Road
P.O. Box 7495
Wilmington, DE 19803

Dale Blaine
PCO SERVICES, INC.
170 Robert Speck Parkway
Mississauga, L4Z 3G1
Ontario, Canada

Tony Bohnert
PURDUE UNIVERSITY
1158 Entomology Hall
West Lafayette, IN 47907-1158

Lisa Brecher
CLOROX TECH. CENTER
P.O. Box 493
Pleasanton, CA 94566

William Brehm
B&G EQUIPMENT CO.
P.O. Box 130
6120 Route 611
Plumsteadville, PA 18949

Nancy L. Breisch
UNIVERSITY OF MARYLAND
1300 Symons Hall
Dept. Of Entomology
College Park, MD 20742-5575

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

Brian Bret
55 Cheverny Ct.
Trenton, NJ 08619

William Broome, Jr.
WHITMIRE RESERACH LABS
6315 Cottonwood Lane
Apollo Beach, FL 33572

Steven Broscious
AMERICAN CYANAMID COMPANY
P.O. Box 400
Princeton, NJ 08543-0400

Sam Bryks
METRO TORONTO HOUSING AUTHORITY
365 Bloor St. E. Ste 8000
Toronto, M4W 3L4
Ontario, Canada

Cathleen Burge
ACRI-MOBAY RESEARCH PARK
17745 S. Metcalf Ave.
Stilwell, KS 66085

Susan Burkart
AMERICAN CYANAMID CO.
P.O. Box 400
Princeton, NJ 08543-0400

David Bybee
SC JOHNSON & SON
1525 Howe St.
Racine, WI 53403-5011

Brian Cabrera
209 Goodrich Dr.
Riverside, CA 92507

Martha Carlson
WALTHAM CHEMICAL CO.
817 Moody Street
Box 538
Waltham, MA 02254

Michael Chambers
DOWELANCO
845 Crossover Lane, Ste. 134
Memphis, TN 38117

John Chapman
TERMINIX INTERNATIONAL
855 Ridge Lake Blvd.
Memphis, TN 38120

C.M. Childers
MILES
P.O. Box 4913
Hawthorn Road
Kansas City, MO 64120-0013

Chris Christensen
URBAN INSECT SOLUTIONS
1420 Jandymar Court
Lexington, KY 40517

Janice Cicchetti
WHITMIRE RESEARCH LABS
27 Morris Dr.
St. Louis, MO

Drew Cloud
AMERICAN CYANAMID CO.
Ag Division
One Cyanamid Plaza
Wayne, NJ 07470

Margaret Collins
1642 Primrose Rd. N W
Washington, DC 20012

J.L. Coltharm
CHEVRON CHEMICAL CO.
6001 Bollinger Canyon Rd.
San Ramon, CA 94583

Richard Cooper
COOPER PEST CONTROL
351 Lawrence Station Road
Lawrenceville, NJ 08648

Selena Crenshaw
P.O. Box 1847
Rocky Ford Road
Valdosta, GA 31603

David Crockett
C/O AIRRIGATION ENG. CO.
1279 Quarry Lane, Suite C
Pleasanton, CA 94566

William Crump
601 S. Oakwood Ave.
Beckley, WV 25801

Gary Curl
WHITMIRE RESEARCH LABS
3568 Tree Court Ind. Blvd.
St. Louis, MO 63122

Anthony Curtis
AUBURN UNIVERSITY
Dept. Of Entomology
301 Funchess Hall
Auburn, AL 36849

Richard Daum
3922 Angelton Court
Burtonsville, MD 20886

Vern Davis
P.O. Box B
New Bern, NC 28563

Kevin Delaney
4202 E Indian River Rd.
Chesapeake, VA 23325-3006

Joe Demark
PURDUE UNIVERSITY
Dept. Of Entomology
1158 Entomology Hall
West Lafayette, IN 47907-1158

Don Devries
DOWELANCO
Letcombe Laboratory
Letcombe Regis
Wantage, OX12 9JT
Oxon, England

Bud Dietrich
NISUS CORP
101 Concord St., North
Knoxville, TN 37919

Pat Dietrich
NISUS CORP
101 Concord St., North
Knoxville, TN 37919

Jeff Dobbs
1095 Applecross Dr.
Roswell, GA 30075

Bonny Dodson
NPCA
8100 Oak Street
Dunn Loring, VA 22027

William Donahue
ZOECON CORP
12200 Denton Dr.
Dallas, TX 75234

Jim Dotson
MILES, INC.
Specialty Products R & D
R D #3, Box 3917
New Tripoli, PA 18066

Tim Drake
CLEMSON UNIVERSITY
Dept. Of Entomology
Clemson, SC 29634-0365

Michael Dryden
1611 Green Valley Circle
Manhattan, KS 66502

Hongyu Duan
ECOSCIENCE LABS
85 N. Whitney St.
Amherst, MA 01002

David Dudor
SC JOHNSON & SON
1525 Howe St.
Racine, WI 53403-5011

Gene Dupree
NORTH CAROLINA STATE UNIVERSITY
Box 7613
Raleigh, NC 27695-7613

Jeff Edwards
DOWELANCO
2800 Mitchell Dr.
Walnut Creek, CA 94589

John Edwards
CENTRAL SCIENCE LABORATORY
Ministry Of Agriculture
London Road
Slough Berks, SL3 7HJ
England

Pete Egan
NAVAL FACILITIES
Engineering Command
Code 1634 A, 200 Stovall St.
Alexandria, VA 22332-2300

Michael Ellenberger
AUBURN UNIVERSITY
Dept. Of Entomology
Auburn, AL 36849

Barry Engroff
AMERICAN CYANAMID CO.
P.O. Box 400
Princeton, JN 08543-0400

Thomas Fasulo
UNIVERSITY OF FLORIDA
Dept. Of Entomology
Bldg. 970, Hull Rd.
Gainesville, FL 32611-0740

M.J. Faulkner
NOR-AM CHEMICAL CO.
P.O. Box 7495
Wilmington, DE 19803

Harlan Feese
ORKIN
2170 Piedmont Rd. N.E.
Atlanta, GA 30324

Peter J. Fitzgerald
P.O. Box 1720
Grand Cayman
British West Indies,

S.J. Flashinski
S.C. JOHNSON & SON
1525 Howe Street
Racine, WI 53403-5011

Michael Fletcher
SMITH KLINE BEECHAM
Animal Health
1600 Paoli Pike
Westchester, PA 19380

Dan Forey
4230 West Swift Ave.
Fresno, CA 93722

Dan Forey
4230 West Swith Ave
Fresno, CA 93722

Brian Forschler
GEORGIA EXP. STATION
Dept. Of Entomology
Griffin, GA 30223-1797

Joanne Frankowski
U.S. BORAX CHEMICAL CO.
3075 Wilshire Blvd.
Los Angeles, CA 90010

Austin Frishman
AMF PEST MGMT
30 Miller Road
Farmingdale, NY 11735

Thomas Gallo
ICI AMERICAS, INC.
Rt. 1 Box 117
Whitakers, NC 27891

Stan Galyon
NISUS CORP
101 Concord St. North
Knoxville, TN 37919

Christine Garcia
4403 Romlon St.
Beltsville, MD 20705

Bill Gebhart
NAVAL FACILITIES
Engineering Command
200 Stovall St.
Alexandria, VA 22332-2300

Ramon Georgis
BIOSYS
1057 East Meadow Circle
Palo Alto, CA 94301

Harvey Gold
NPCA
8100 Oak Street
Dunn Loring, VA 22027

Roger Gold
TEXAS A&M UNIVERSITY
Dept. Of Entomology
College Station, TX 77843

Jill Gordon
CLEMSON UNIVERSITY
Dept. Of Entomology
Clemson, SC 29634-0365

Richard Gorham
FDA HFF-237
200 C Street S.W.
Washington, DC 20204-0001

Richard Gouger
ICI AMERICAS INC.
Delaware Corporate Center I I
Wilmington, DE 19897

Ken Grace
UNIVERSITY OF HAWAII
Dept. Of Entomology
3050 Maile Way, Rm. 310
Honolulu, HI 96822-2271

Theodore Granovsky
GRANOVSKY ASSOCIATES
3206 Wilderness Rd.
Bryan, TX 77801

Stanley Green
PENN STATE UNIVERSITY
4601 Market Street
3rd Floor
Philadelphia, PA 19139

Albert Greene
NCR IPM PROGRAM
Building Services Sec. W P M O B
G S A, R O B, Rm. 7719, 7th & D, S W
Washington, DC 20407

Michael Gregory
FUMEX
40 Roselle Ave.
Mineola, NY 11501

Erich Grove
CLEGG'S PEST CONTROL
P.O. Box 3089
Durham, NC 27715

Kevin Haack
GRANOVSKY ASSOCIATES, INC.
3206 Wilderness Rd.
Bryan, TX 77801

Ross Halliday
RICERCA INC.
7528 Auburn Rd.
Plainesville, OH 44077

Bob Hamilton
JOHNSON WAX
1525 Howe St. Ms167
Racine, WI 53226

Mike Hamilton
616 Kalorama Rd.
Skyesville, MD 21784

Philip Hamman
TEXAS A&M UNIVERSITY
Dept. Of Entomology
College Station, TX 77843-2475

Laurel Hansen
SPOKANE FALLS COMM. COLLEGE
W 3410 Ft. Wright Drive
Spokane, WA 99204

Jerrold Harris
TEXAS A&M UNIVERSITY
Center For Urban & Public Health
College Station, TX 77843-2475

Michael Haverty
US FOREST SERVICE
P.O. Box 245
Berkeley, CA 94701

Douglas Hayes
WATCH ALL, INC.
1109 Washington St.
Weymouth, MA 02189

Stoy Hedges
TERMINIX INTERNATIONAL
855 Ridge Lake Blvd.
Memphis, TN 38120

Kathy Heinsohn
3007 Courthouse Dr. 3d
West Lafayette, IN 47906

Gregg Henderson
LOUISIANA STATE AG CTR.
Dept. Of Entomology
Baton Rouge, LA 79893

Douglas Hepler
CIGA-GEIGY ANIMAL HEALTH
P.O. Box 18300
Greensboro, NC 27419

Akio Higo
MCLAUGHLIN GORMLEY KING
8810 Tenth Ave. North
Minneapolis, MN 55427

Nancy Hinkle
P.O. Box 14565
Gainesville, FL 32604

John Ivey
MOBAY CORPORATION
P.O. Box 4913
Kansas City, MO 64120

Herbert Jacobi
NATIONAL INST. HEALTH
9000 Rockville Pike
Bldg. 13/6807
Bethesda, MD 20892

Steve Jacobs
PENN STATE UNIVERSITY
513 A S I Bldg.
University Park, PA 16802

James Jarratt
MISSISSIPPI STATE
Dept. Of Entomology
P.O. Box 5446
Miss. State, MS 39762

Eric Jessen
P.O. Box 2456
Breckenridge, CO 80424

David Johnson
ROUSSELL BIO CORP.
170 Beaverbrook Road
Lincoln Park, NJ 07035-1495

Robert Johnson
11637 Boiling Brook Pl
Rockville, MD 20852

David Jones
ORKIN
2170 Piedmont Rd. N E
Atlanta, GA 30324

Richard Judy
1012 W Lunt Ave
Schaumburg, IL 60193

Ulrich Kalkofen
2258 Darbytown Road
Richmond, VA 23231

Shripat Kamble
UNIVERSITY OF NEBRASKA
101 Natural Resources Hall
Lincoln, NE 68583-0818

Tom Kandathil
SC JOHNSON WAX
1525 Howe Street
Racine, WI 53403

Jeffrey Kane
ECOSCIENCE LABS
85 N Whitney St.
Amherst, MA 01002

Harry Katz
Berkshire E 3076
Deerfield Beach, FL 33442

David Keith
UNIVERSITY OF NEBRASKA
Dept. Of Entomology
Lincoln, NE 68583-0816

Kenneth Kendall
TERMINIX CO.
P.O. Box 2587
Fayetteville, NC 28314

William Kern
UNIVERSITY OF FLORIDA
Dept. Of Entomology
Gainesville, FL 32611

Ed King
3905 Vincennes Rd. Ste 200
Indianapolis, IN 46268

John Klotz
PURDUE UNIVERSITY
1158 Entomology Hall
West Lafayette, IN 47907-1158

Ronald Knight
RECKITT & COLMAN
179 Commerce Rd
Carlstadt, NJ 07072

Ronald L. Knight
RECKITT & COLMAN HOUSEHOLD PRODUCTS
179 Commerce Road
Carlstadt, NJ 07072

Philip Koehler
UNIVERSITY OF FLORIDA
Dept. Of Entomology
1600 S W 23 Dr
Gainesville, FL 32608

Phillip Kongshaug
SC JOHNSON WAX
1525 Howe St. M S 153
Racine, WI 53403-5011

Robert Kopanic
NORTH CAROLINA STATE UNIV.
Dept. Of Entomology
Raleigh, NC 27695-7613

Ingrid Korber
SCHONUNGSWEG 5
0 A A 66
Berlin,
Germany

Sandy Kraft
PINTO & ASSOC. INC.
914 Hillcrest Dr.
Vienna, VA 22180

Charles Kramer
UNIVERSITY OF MARYLAND
Physical Plant
College Park, MD 20742

Richard Kramer
NPCA
18100 Darnell Dr.
Olney, MD 20832

Joseph Krause
SC JOHNSON & SON
1525 Howe St.
Racine, WI 53403-5011

Frances Lechleitner
1202 Remington
Fort Collins, CO 80524-3732

Don Lesiewicz
FAIRFIELD AMERICA CORP.
809 Harrison Street
Frenchtown, NJ 08825

Donald Lewis
IOWA STATE UNIVERSITY
Dept. Of Entomology
104 Insectary
Ames, IA 50011

Vernard Lewis
UC BERKELEY
Dept. Of Entomology
Berkeley, CA 94720

Trevor Lubbert
Bldg. 13 Room G807
9000 Rockville Pike
Bethesda, MD 20892

Dottie Lund
1009 Sedwick Drive
Wilmongton, DE 19803

Stephen Manweiler
BIOSYS
1057 East Meadow Circle
Palo Alto, CA 94303

Joseph Mares
GRIFFIN CORP
P.O. Box 1847
Rocky For Road
Valdosta, GA 31603-1847

Nicole Marino
ROUSSEL BIO CORP
170 Beaverbrook Road
Lincoln Park, NJ 07035-1495

Lonnie Matthews
ASPCRO
P.O. Box 3 A Q
Las Cruces, NM 88003-0005

Kathe Mccollum
WALTHAM CHEMICAL CO.
817 Moody Street
Box 538
Waltham, MA 02254

Yash Mehra
RECKITT & COLMAN
179 Commerce Rd.
Carlstadt, NJ 07072

Roger Meola
TEXAS A&M UNIVERSITY
Dept. Of Entomology
College Station, TX 77843-2475

Michael Merchant
TEXAS AG EXTENSION SVC
17360 Coit Road
Dallas, TX 75252

Walker's Mill
E.I. DU PONT DE NEMOURS
Barley Mill Plaza
Wilmington, DE 19898

Harry B. Moore
DM ASSOCIATES
3725 Eakley Court
Raleigh, NC 27606

Gordon Morrison
CLOROX CO.
3030 L B J Freeway
Suite 1220, L B 38
Dallas, TX 75234

James Moss
USDA-ARS-MAVERL
P.O. Box 14565
Gainesville, FL 32604

E.W. Moyses
CIGA-GEIGY LTD
R-1062.P.03
Ch-4002
Basle,
Switzerland

Thomas Myers
223 Big Run Road
Lexington, KY 40503

Tim Myles
FAC. FORESTRY
33 Willcocks St.
Toronto
Ontario, M55 3133
Canada

David Naffziger
WHITMIRE RES LABS, INC.
3568 Tree Court Ind. Blvd.
St. Louis, MO 63122

Kurt Nelson
1525 Howe St. M S 167
Racine, WI 53406

Jay Nixon
AMERICAN PEST MANAGEMENT
6460 New Hampshire Ave.
Takoma Park, MD 20912

Mark Noirot
U.S. BORAX RESEARCH
412 Crescent Way
Anaheim, CA 92801

Maureen O' Shea
KILLGERM CHEMICALS
P.O. Box 2, Denholme Dr.
Ossett, W
Yorkshire, WF5 9NB
England

Richard F. O' Shea
ALTERNATIVE PEST CONTROL
85 Hollingworth Road
Littleborough
Lanc, OL 15 OAZ
England

David Oi
UNIVERSITY OF FLORIDA
Dept. Of Entomology
Bldg. 970, Hull Rd.
Gainesville, FL 32611-0740

Faith Oi
UNIVERSITY OF FLORIDA
Dept. Of Entomology
Bldg. 970, Hull Rd.
Gainesville, FL 32611

Jim Olsen
TEXAS A&M UNIVERSITY
Dept. Of Entomology
College Station, TX 77843

Christian Oseto
PURDUE UNIVERSITY
Dept. Of Entomology
West Lafayette, IN 47906-1158

Sally Osier
AGRISENSE
3250 W. Ellery
Fresno, CA 93711

John Paige
986 25th St.
Vero Beach, FL 32960-5016

Kathy Palma
TEXAS A&M UNIVERSITY
Dept. Of Entomology
College Station, TX 77843-2475

Vincent Palmere
NISUS CORP.
101 Concord St. North
Knoxville, TN 37919

Charlie Pate
4418 Briers Place
Stone Mountain, GA 30083

Richard Patterson
USDA-ARS-MVERL
1600 23 Dr.
Gainesville, FL 32604

Hal Paul
MILES INC.
9 Roosevelt Way
Avondale, PA 19311

Robert Pierce
ZOECON
112200 Denton Drive
Dallas, TX 75234

Jeff Pinkham
DOWELANCO
Quad 4
9002 Purdue Road
Indianapolis, IN 46268-1189

Larry Pinto
PINTO & ASSOC., INC.
914 Hillcrest Dr.
Vienna, VA 22180

Bill Plapp
TEXAS A&M UNIVERSITY
Dept. Of Entomology
College Station, TX 77843

David Pontes
NEW ENGLAND PEST CONTROL
161 Connell St.
Providence, RI 02905

Salvatore Porcellini
OCEAN PEST CONSULTANTS, INC.
P.O. Box 1032
117 Rt. 9
Forked River, NJ 08731

Michael Potter
UNIVERSITY OF KENTUCKY
S225 Ag. Science Center N
Lexington, KY 40456-0081

Lindsey Potts
IPM SYSTEMS
P.O. Box 291089
San Antonio, TX 78229

Peggy Powell
WVU EXTENSION SERVICE
414 Brooks Hall
Morgantown, WV 26506

Paul Rensner
AMERICAN CYANAMID CO.
60 Misty Pine Rd.
Fairport, NY 14450

Clyde Roberts
DU PONT CO.
Agricultural Products
P.O. Box 80038: W M 4-132
Wilmington, DE 19880-0038

Sterett Robertson
DOWELANCO
Quad I V
9002 Purdue Road
Indianapolis, IN 46268-1189

Bill Robinson
VIRGINIA TECH
Dept. Of Entomology
Urban Pest Control Res. Ctr.
Blacksburg, VA 24061-0319

Thomas Rogers
P.O. Box 9811
Jackson, MS 39286

Steven Rogosheske
MCLAUGHLIN GORMLEY KING CO.
8810 10th Ave. N
Minneapolis, MN 55427

Mary Ross
VPI
Dept. Of Entomology
Blacksburg, VA 24061

Dick Rudin
SC JOHNSON WAX
1525 Howe St.
Racine, WI 53403-5011

Michael Rust
UNIVERSITY OF CALIFORNIA
Dept. Of Entomology
Riverside, CA 92521

Frederick J. Preiss
MGK
8810 Tenth Ave. North
Minneapolis, MN 55427-4372

Maureen Puettmann
USDA FOR. SERV.
P.O. Box 2008 6 M F
1924 34th St.
Gulfport, MS 39505

George Rambo
521 Dakota Dr.
Herndon, VA 22070

John Randall
SC JOHNSON & SON, INC.
Entomology Research Center
Mall Station 401
Racine, WI 53406

George Raymond
NOR-AM CHEMICAL CO.
3509 Silverside Rd.
Wilmington, DE 19803

Lon Records
TARGET
P.O. Box 117
Cerritos, CA 90701

Byron Reid
PURDUE UNIVERSITY
1158 Entomology Hall
West Lafayette, IN 47907-1158

Donald Reierson
UNIVERSITY OF CALIFORNIA
Dept. Of Entomology
Riverside, CA 92521

Eve Reitz
UNIVERSITY OF MARYLAND
Physical Plant Dept.
General Services Division
College Park, MD 20742

Jack Ryder
DOWELANCO
1800 Parkway Place, Ste. 1030
Marietta, GA 30067

Sunny Ryerson
P.O. Box 1812
Waterbury, CT 06722

Ron Sbragia
DOWELANCO
Quad 3/4
9002 Purdue Road
Indianapolis, IN 46268-1189

Coby Schal
RUTGERS UNIVERSITY
Cook College, Dept. Of Ent.
P.O. Box 231
New Brunswick, NJ 08903

Mike Scharf
2324 Northwestern Ave.
West Lafayette, IN 47906

Rudolf Schenker
CIGA-GEIGY LTD
R-1001 B P 76
Postfach
C H - 4002, basel
Switzerland

Brian Schneider
DOWELANCO
9550 Zionsville Rd.
Bldg. #302
Indianapolis, IN 46268

Bonnie Semilof
1350 I St. N W
Washington, DC

Patrick Settle
4418 Briers Place
Stone Mountain, GA 30083

Philip Seymour
WALTHAM CHEMICAL CO.
817 Moody St. Box 538
Waltham, MA 02254

Umar Shadab
AMER. MUSEUM NAT. HISTORY
Dept. Of Entomology
79 St. C P W
New York, NY 10024

Zia Siddiqi
PCO SERVICES, INC.
170 Robert Speck Parkway
Mississauga
Ontario, L4Z 3G1
Canada

Jerry Siegfried
J.C. EHRLICK CO., INC.
840 William Lane
Reading, PA 19612

Charles Silcox
FAIRFIELD AMERICAN CORP.
809 Harrison St.
Frenchtown, NJ 08825

Jules Silverman
7200 Johnson Drive
Pleasanton, CA 94588

Eric Smith
DODSON BROTHERS
P.O. Box 10249
Lynchburg, VA 24506

Jim Smith
UNIVERSITY OF CALIFORNIA
Dept. Of Entomology
Riverside, CA 92521

Lane Smith
AUBURN UNIVERSITY
Dept. Of Entomology
Funchess Hall
Auburn, AL 36839

Eric Snell
222 Catocin Circle
Suite 205
Leesburg, VA 22075

Nick Spero
INSECT CONTROL & RESEARCH
1330 Dillon Heights Ave.
Baltimore, MD 21228-1199

Forrest St. Aubin
SUMMA PEST MGMT. SERVICES
10520 Barkley
Overland Park, KS 66212

Dave Steiger
997 Old Eagle School Road
Suite 220
Wayne, PA 19087

Nick Stone
VPI & SU
Dept. Of Entomology
Blacksburg, VA 24060

Daniel Stout
WHITMIRE RES LABS, INC.
3568 Tree Court Ind. Blvd.
St. Louis, MO 63122

Daniel Stoutt I I
N.C. STATE UNIVERSITY
Dept. Of Entomology
Raleigh, NC 27695-7613

Fred Strickland
TERMINIX TRAINING DIV.
5490 Government Blvd.
Mobile, AL 36693

Nan-yao Su
FT. LAUDERDALE RESEARCH
University Of Florida
3205 College Ave.
Ft. Lauderdale, FL 33314

Amy Suggars Downing
CHEMLAWN R&D CENTER
135 Winter Rd.
Delaware, OH 43015

Daniel Suiter
UNIVERSITY OF FLORIDA
Dept. Of Entomotogy
Bldg. 970, Hull Road
Gainesville, FL 32611

Daniel Suomi
WASHINGTON STATE UNIVERSITY
Dept. Of Entomology
168a F S H M
Pullman, WA 99164-6382

Wayne Surles
NOR-AM CHEMICAL CO.
3509 Silverside Rd.
Wilmington, DE 19803

Douglas Sutherland
125 Lakeside Dr.
Greenbelt, MD 20770

Joseph Tarnopol
US ARMY DIRECTORATE OF PUBLIC WORKS
Bldg. 203, Ft. Myer
Arlington, VA 22211-5050

Claude Thomas
B&G EQUIPMENT CO.
P.O. Box 130
6120 Route 611
Plumsteadville, PA 18949

Ellen Thoms
DOWELANCO
5100 W. Kennedy Blvd.
Suite 450
Tampa, FL 33609

Barbara Thorne
UNIVERSITY OF MARYLAND
Dept. Of Entomology
1300 Symons Hall
College Park, MD 20742-5141

Barbara Tiernan
1279 Quarry Lane, Suite C
Pleasanton, CA 94566

Vern Toblan
75 Chrome Rdd.
Nottingham, PA 19362

Robin Todd
INSECT CONTROL & RESEARCH
1330 Dillon Heights Ave.
Baltimore, MD 21228-1199

Sherman Trimm
FMC CORP
P.O. Box 8
Princeton, NJ 08543

Jeffrey Tucker
P.O. Box 70375
Houston, TX 77270

Doug Van Gundy
ZOECON CORP.
12200 Denton Dr.
Dallas, TX 75234

Ed Van Istendal
THE WYOMISSING GROUP
P.O. Box 6589
Wyomissing, PA 19610

Christopher Voglewede
PURDUE UNIVERSITY
1158 Entomology Hall
West Lafayette, IN 47807-1158

Richard Wadleigh
S.C. JOHNSON & SON
M.S. 167
1525 Howe St.
Racine, WI 53403

Michael Waldvogel
N.C. STATE UNIVERSITY
Dept. Of Entomology
Box 7613
Raleigh, NC 27695-7613

Deborah A. Waller
OLD DOMINON UNIVERSITY
Biology Dept.
Norfolk, VA 23529

Terry Weber
BIOSYS
107 E. Meadow Circle
Palo Alto, CA 94303

Phyllis Weintraug
INSECT CONTROL & RESEARCH
13300 Dillon Heights Ave.
Baltimore, MD 21228-1199

Jeff Welker
DOWELANCO
9002 Purdue Road
Quad 3/3
Indianapolis, IN 46268

Charles White
BOLLING AFB
Entomology Dept.
1100 C.E.S/ C.E.M.H.H.E.
Washington, DC 20332-5000

Richard Whitman
601 S. Oakwood Ave.
Beckley, WV 25801

Susan Whitney
UNIVERSITY OF DELAWARE
Dept. Of Entomology
Newark, DE 19717-1303

John Wickham
INCON CONSULTANTS
Draycott
Churchwalk, Bletchley
Milton Keynes, MK36DQ
England

K.B. Widley
MINISTRY OF AGRICULTURE
Fisheries And Food
Staplake Mount
Starcross, Exeter, EX6 8PE
Devon, England
Karin Louise Wilhelmi
9962 Guilford Rd. #302
Jessup, MD 20794

Kirk Williams
CLEMSON UNIVERSITY
Dept. Of Entomology
Clemson, SC 29634-0365

Neil Williams
ICI PUBLIC HEALTH
Furnhurst, Haslemere
Surrey, GU27 3JE
England

James Willut
FMC CORP
P.O. Box 8
Princeton, NJ 08543

Marijo Wilson
URBAN INSECT SOLUTIONS
1420 Jandymar Court
Lexington, KY 40517

Ron Winslow
ZOECON CORP.
12200 Denton Dr.
Dallas, TX 75234

Jim Wolfe
7200 Johnson Drive
Pleasanton, CA 94588

Jo Ellen Woody
ICI AMERICAS INC.
Route 1 Box 117
Whitakers, NC 27891

Charles Wright
NORTH CAROLINA STATE
Dept. Of Entomology
Raleigh, NC 27695-7613

Clayton Wright
10539 Maybank
Dallas, TX 75220

James Yonker
SC JOHNSON & SON
1525 Howe St.
Racine, WI 53403-5011

Brian Zeicher
US ARMY ENV. HYGIENE AGENCY
Attn: Entomological Sciences Div.
Aberdeen Proving Ground, MD 21010-5422

Jing Zhai
VA TECH
Dept. Of Entomology
Urban Pest Control Res. Center
Blacksburg, VA 24061-0319

Pat Zungoli
CLEMSON UNIVERSITY
Dept. Of Entomology
Clemson, SC 29634-0365