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URBAN PEST CONTROL - A STRONG FOUNDATION

John V. Osmun
Professor Emeritus, Purdue University

Today, I am very fortunate — in two ways. First, it is an honor to address this conference. Here it is just 10 years old and already well regarded. Fifteen years ago there were a lot of people in entomology who wouldn't have thought the conference was needed or justified, nor would they have bet 2¢ it could have succeeded. Your founders, planners and participants have proved them wrong. Secondly, this is a dedicated lecture. For years I have listened to colleagues at the ESA annual meeting give invitational addresses honoring someone, e.g., Comstock, Wheeler, etc. The speaker frequently didn't know the distinguished entomologist and some didn't even say a word about him. In my case, however, Arnold Mallis was a friend of mine who gave me valuable counsel in my early days. He was a willing cooperator. I can recall for example, the many times back in the early 50s when he supplied us with CSMA standardized house flies. He was a dedicated entomologist and a strong supporter of the pest control industry. Arnold was a true urban entomologist at a time when there weren't many around. I couldn't be more pleased than to be a part of our continuing recognition of this outstanding man.

The term "pest control" has come to mean many things. The original connotation referred to pests associated with man's welfare, especially those in structures -- thus, structural pest control. It is properly identified as the activity of managing insects, other arthropods and vertebrate pests in homes, business establishments, manufacturing plants, health-care and municipal buildings, as well as outdoor areas frequented by man. Curiously, the word "pest" as a generic connotation did not come into use until the mid 1930s. Prior to then it was specific: lice, bedbugs, cockroaches, rats. Occasionally, they were all grouped together as "vermin."

In recent years, the term "pest control" has been expanded by some to include those insects attacking agricultural crops, nurseries and forests. As discussed here today, pest control retains its original connotation. Fortunately, many now refer to it as urban pest control and that makes it pretty clear to everyone. From the economic perspective, it is the principal business expression of entomology. Happily, today it also includes a large measure of research, extension, teaching and extensive pest management practices.

The subject I've been given for discussion today is a good one: Urban pest control, a strong foundation. It is multi-faceted, depending on one's interpretation. Perhaps it refers simply to the belief that pest control, as a business, has moved quickly off the blocks, but that is not really so. Or perhaps it is that urban entomology is showing a strong position as a fledgling within the science of entomology. On the other hand, one might ask: "a strong foundation for what?" Well, many things. A young person considering business and having received a good education in urban and industrial entomology will find it a stepping stone to a successful career. If it's international work in an urban environment, pest control experience will open many doors. And, especially important for us today, is the

fact that urban entomological research is a marvelous spin-off from years of structural pest control as an occupation. My intention is to weave all of the facets of the title into my talk.

In order to appreciate where we are today, we need to step back in time and examine in a cursory fashion the history of urban pest control. We have to look back centuries to find a beginning. Perhaps it was that monkeys scratched because they itched from fleas and lice. Whatever, from the beginning, man has been concerned with organisms occurring where someone or something didn't want them. It is true today and the objectives remain unchanged. As man has evolved and lived more gregariously, he has acquired more pests and has sought the means to control them.

The early records, mostly from Europe, speak of exterminating and vermin control. Much of the activity was health-related with frequent references to plague and typhus. Some records have evolved as folklore such as that of the Pied Piper which arose from two outbreaks of plague in Germany over a 13-year span of time (13th Century). Organized pest control dates back to 1695 when H. Tiffin and Son formed a company in England first to combat the brown rat, and later, bed bugs. The company was also concerned with insects in supplies and food stockpiled for war. (War has been a catalyst for many advances in our discipline.) Many of our early American exterminators were immigrants from England and Germany. They brought with them a measure of experience in control and often chemistry; they worked pretty much as individuals. They were dealing with a number of pests that they knew, pests that had only recently been introduced from abroad: house mice, Norway rat, bed bugs, and certain cockroaches and fleas. For those of you who enjoy early records and antidotes, you can find them detailed by both Davis (1961) and Snetsinger (1983).

It was the 19th century before the business of pest control commenced in the United States. The acknowledged first was Solomon Rose, an ethical gentleman from Cincinnati who in 1842 founded Rose Exterminator Company. Later the firm expanded through a chain of associates and to this day, some of our finest PCOs are Rose people. Again, war was one catalyst; this time the Civil War. Solomon supplied the government with large quantities of pyrethrum powder for control of lice, bed bugs and cockroaches. The company is also credited with the first use of phosphorus paste and, early on, bed bug control was carried out by them using a feather dipped in kerosene. The success of the Rose organization led to other notable firms; e.g., Jesse Getz (duster), Nathan Sameth, Theodore Meyer, Otto Orkin. They established that urban pest control is a service to mankind.

The number of pest control firms ballooned in the post World War I years of the 1920s and into the 30's. For most of you, the 30s must be ancient history. As for me, that era was my youth! I was part of what young people today read as history, so I can relate to it and help keep the record straight. For starters, I remember well when house flies were everywhere in great abundance. We always hung a sticky ribbon in our kitchen to catch the flies. I recall taking the ribbon with one week's collection to a friend's house on Saturday evening to compare catches. His ribbon had collected 385 flies, but I beat him: ours had 410! Bedbugs and cockroaches were abundantly common. At best, our controls were Flit sprayed copiously for short-term relief. The advertising slogan of the day was: "Quick, Henry, the Flit!"

At that time, I knew only a few pest control fellows and I wasn't particularly attracted to them. Image-wise, there existed much public suspicion. Too many unprepared and often fraudulent persons had slipped into the business, tainting its reputation. There was no accountability and there were "secret" formulae, black boxes, and unmarked cars, all of which were unfortunate symbols of the industry. Fortunately, there was a core of excellent

operators who made those years a time when the pest control industry took some gigantic steps forward. In 1933, at the depth of the Depression and under Roosevelt's New Deal, the NRA (National Recovery Administration) passed Congress. It required that businesses, through their trade associations, establish codes of fair trade practices. Therefore, that fall there was formed the National Association of Exterminators and Fumigators. Three years later it changed its name to the National Pest Control Association (NPCA). That was the first time the generic term "pest" had been used. The driving force behind all this was William O. Buettner, a New York exterminator. He was elected the Association's first president and then served unselfishly as executive secretary through the ensuing years of growth until his untimely death in 1953. I knew him well and was on special assignment with him at the time of his passing. What a person! He was a visionary leader who stood fearlessly above the crowd. No better example ever existed for Emerson's definition: "An institution is the lengthened shadow of one man."

It was an important happening (much more than coincidence) that in the mid 1930s the educational aspects of urban pest control also got off the ground. We must remember that at that time entomologists and others scoffed at or ignored those engaged in exterminating. It was at this time that Professor J. J. Davis of Purdue stuck his neck out. He was an inquisitive individual, yet he had always been a devoted promoter of his discipline, entomology. Unexpected, Davis showed up in Detroit in 1935 at the third convention of the Association "to see what these fellows looked like." There he met Bill Buettner. Two years later he initiated the Purdue Pest Control Conference and at that time, also, Howard Deay (Purdue) coined the term "PCO" (Pest Control Operator). Davis introduced the PCO's to the University community and the University to the pest control industry. Thus, meaningful communication began and the walls of prejudice commenced to come tumbling down.

So it was that the two men, Buettner and Davis, put in place the initial strong foundation of urban pest control. The dedication found in the book *Scientific Guide to Pest Control Operations* tells it best.

"Dedicated to William Oscar Buettner and Professor John June Davis

--One, the first leader of the pest control industry

--One, the pioneering entomologist who put principles into pest control

--Both, who together started this industry on the road to service and greatness."

There were, therefore, positive aspects of the 30s and they carried over into the 1940s. Remember, America was lean and hungry and ready to advance; this was evident as the country plunged into the drama of World War II. There were special problems: chemical shortages, critical insect-borne diseases, and inadequate controls. Gradually, we heard stories of a striking new chemical slowing malaria in the South Pacific and abruptly stopping typhus in the population of Naples. It became a major factor in winning the war. Finally, there was revealed that the chemical was DDT, and immediately the public demand for it soared. DDT was a bonanza for the pest control industry, yet it was almost by chance that its properties were discovered. In tests at the Orlando USDA laboratory, its initial kill of body lice was unimpressive; but because the tests were run on a Friday, the test dishes were not scheduled for cleanup until Monday. An observant entomologist noticed that all the lice were, by that time, dead! It was the advent of slow acting, long-residual pesticides: lucky accident; great discovery; the prepared mind! For young researchers, this is a point to remember.

So began an explosion of new pesticide chemicals and, with it, the beginning of extensive studies relating to their uses in the urban environment. By 1947, some regulation of registration was deemed necessary and Congress passed the initial version of The Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). Educational conferences for

pest control operators were being offered in several states; a 4-year curriculum in urban and industrial entomology commenced at Purdue; two students developed the B&G sprayer; and in 1950 Pi Chi Omega was chartered as a professional fraternity composed principally of entomologists associated with pest control.

The 1950s saw a startling array of contrasts. It became an era of unbridled chemical use with virtually no hint of restraint or constraint. Some people predicted that the pest control industry might soon be out of business: the chemicals were just too good. Man believed himself to be in total command of nature. There were signals to the contrary, however, and some scientists viewed them with alarm. Most notable and most unexpected was the rather rapid development of insect resistance to a number of wonder chemicals; e.g., flies to DDT and related compounds, German cockroaches to chlordane. There was evidence of an imbalance between certain species and the depletion in the numbers of predators and parasites. Robins were dying on the campus of Michigan State University, where earthworms soaked up the insecticides beneath the trees heavily sprayed to control vectors of Dutch elm disease.

But the general feeling was that even "if there were a few problems, not to worry, there soon would be new chemicals to replace those in trouble." Yes, and to compound the problems for urban pest control.

The 1960's witnessed the advent of environmentalists. Rachel Carson, in '62, published her book *Silent Spring* — a devastating yet eloquent and compelling denunciation of pesticides. Carson was a gifted and often honored author; and this acclaim, coupled with her reputation as a wildlife biologist, provided an air of credibility. Her supporters hailed her as apocalyptic. She uncovered and then revealed environmental problems and she was prophetic in her expression of fear for the future of our environment. At the same time, there were even more who condemned her, including some scientists caught up in their own little areas of success: agriculturists fearing the loss of yield-enhancing pesticides, and a large segment of the manufacturing and using industries. It was easy to dislike her. There were numerous technical errors in her arguments but, as Mason accurately put it, the book "is a passionate and convincing discourse on real, presumed, and potential ecological dangers." It is filled with accusations of broad neglect.

However we view *Silent Spring*, we should be thankful that it was Carson —not the government regulatory agencies and not the media —that awakened us from our misdirected complacency. As startled and defensive as many were at the time, there arose a new awareness of ecology and the environment and new avenues of research began to appear. The major spin-off from initial accusations about a few insecticides was the crescendo of public outcry over all types of environmental contamination: smog, smoking, belching chimneys, foul water, and waste. Pesticides in their entirety were caught up in this tide of discontent; soon, worthy chemicals were falling on the battlefield of public controversy! For the moment the image of pest control was seriously tainted.

The anxiety of the '60s carried over into action in the 1970s. For example, DDT was condemned and banned without its day in court. In one generation, it went from the most wanted to the "most wanted for execution." This era became one of laws and regulations. As a result of public pressure regarding environmental issues, both the Executive Branch and Congress responded. First, the EPA was established (1970); next, Congress enacted a "new" pesticide law in 1972 by an elaborate amendment of FIFRA. As laws go, it was and is a good one.

- It tightened requirements for pesticide registration.

- It brought considerable uniformity of regulations among the states by requiring compliance laws.
- It included provisions for supporting research.
- It required certification of applicators who apply restricted-use pesticides. This necessitated extensive training. (Most states extended the provision by requiring certification of commercial applicators using any pesticide.)

Initially, certification was not popular among PCOs. That was a surprise to me because the competency standards we established as regulations in 1974 were in large measure patterned after those well accepted in this industry. There is no question but what certification has been a help. After all, the pest control industry is accountable to those it serves, i.e., the public. By chance, I ran across a germane statement made some years ago by Richard Eldridge, then the executive director of NPCA. He wrote, "Certification is the greatest thing that has happened to the using industry. There is no place in our society for poor practitioners." It is very important that at that time, congress provided in FIFRA something we had been seeking for years, namely the legal recognition of the essentiality of education and the competent person in pest control! These were big steps forward — education and research. Indeed, a new era was beginning and urban pest control profited from it.

During the decade of the 1980s, the pest control industry matured toward a truly professional status and urban entomology came into its own. In that era, also, there was an emerging interest in urban pest management to the extent that IPM, or preferably UPM, has become a key buzzword of urban pest control.

We have reviewed the chronology of events that led to today's strong foundation of urban pest control. However, there are a number of important contributing organizations and activities that must be documented because they greatly strengthened our position during this period of growth.

One is the impact of associations. The NPCA has been blessed with good leadership from Buettner to Dr. Ralph Heal (a sound scientist) to Richard Eldridge to Harvey Gold. Its technical staff has included Phil Spear, Doug Mampe, Phil Hamman, Larry Pinto, Dick Carr, George Rambo and Richard Kramer. It has both supported and sponsored a variety of educational programs and extensive research, and is now developing a technician credentialling program. In addition to the national association, many states have developed affiliated associations and these, too, have emphasized education and research.

Secondly, trade magazines have evolved to the point of providing technical material and publishing original research. It all started with Al Cossetta, an enterprising exterminator in Kansas City who had a dream of becoming a publisher. In 1933, he mortgaged all of his possessions and produced the first issue of *Exterminator's Log*. It was a success and it had a favorable impact on the ethics and image of pest control. Later the magazine was known simply as *Pests* and then *Pests and Their Control*. In 1948, he sold the magazine to James A. Nelson who published it as *Pest Control*. During his 25 years, it was first rate journalism and a constant source of education for the industry. For example, it was the initial publisher of the now well-known correspondence course in pest control technology. Another trade magazine surfaced under the name *Pest Control Technology*; it is today an especially timely and provocative publication. The NPCA publishes its own journal, *Pest Management*, which combines association activities and current technical information.

A third consideration is also in the category of publications. Since the mid-thirties, there have been authored a number of books which have, in various ways, provided invaluable information to operators, teachers, and urban entomologists. The following

selected first printing references up through the late 80s, are listed here by author, date and title.

- Kofoed, C.A. 1935- *Termites and Termite Control*
 Hartnack, H. 1939- 202 *Common Household Pests*
 Herms, W. 1945-*Medical Entomology*
 Mallis, A. 1945-*Handbook of Pest Control*
 Snyder, T.E. 1948-*Our Enemy the Termite*
 Hockenyos, G. 1948-*Approved Reference Procedures for Subterranean Termite Control*
 Weinman, C. 1950-*Pest Control Technology (Entomological)*
 Davis, J.J. 1961-*A Contribution To the History of Commercial Pest Control*
 Truman, L.C. & W.L. Butts 1962-*Scientific Guide to Pest Control Technology*
 Hickin, N. 1964-*Household Insect Pests*
 Sweetman, H.L. 1965-*Recognition of Structural Pests and Their Damage*
 Weesner, F. 1965-*Termites of the United States*
 Cromwell, P. 1968-*The Cockroach*
 Ebeling, W. 1975-*Urban Entomology*
 Frankie, G. & C. Koehler 1978-*Perspectives in Urban Entomology*
 Snetsinger, R. 1983-*The Ratcatcher's Child*
 Bennett, G.W. & J.M. Owens 1986-*Advances in Urban Pest Management*

A number of these books have been updated by new authors. Except where they are no longer available, most of these books should be on the shelves of every urban entomologist.

A fourth category comprises a short listing of articles and separates that I personally found invaluable.

Back, Earnest (USDA) 1925-1940-Numerous papers on a wide selection of urban insects.

Gould & Deay 1940-Biology of 6 species of cockroaches which inhabit buildings.

Roth & Willis 1954-The reproduction of cockroaches

Johnson, H. R. 1960-Soil treatment for subterranean termites

Pratt, Harry 1950s & 60s-Identification keys and charts

Osmun & Butts 1966-Pest Control

NPCA Technical Releases 1950 to present.

A fifth category is that of education (classroom teachers and trainers). There are two groups, those at universities who have been or are involved in teaching or conferences, and those who can be classified as trade and consultants (non-university).

University: Alexander, Apel, Bennett, Bray, Butts, Carruth, Cochran, Davis, Deay, Eden, Grayson, Hamman, Herms, Frishman, Lehker, Moore, Oderkirk, Osmun, Robinson (International Conference), Rosewall, Snetsinger, Sweetman, Thorvilson, Charles Wright, Wilber, Wood

Non-University: Brehm, Ehmann, Frishman, Granovsky, Hunt, Mampe, Pinto, Rambo, Stevenson, Truman, Tucker, Clayton Wright, Whitmire.

It would be a major oversight if I omitted the names of important pest control operators who, in various ways, prior to 1980, had an impact on the growth and strength of this

industry. Some of them had an impact on a number of you in this audience. My apologies if I have omitted some whose names should have come to mind. (Those PCO's mentioned previously are not included in this listing.)

Adams, Bedingfield, Blasingame, Brady, Carncross, Clements, Cook, Dold, Edlredge, Elliot, Elo, Felton, Gunn, Harder, Hess, Hockenyos, Houghton, Ives, Jennings, Katz, Lance, McCould, Montgomery, M. Oser, T. Oser, Raley, Redd, Ritt, Russell, Sameth, Schnorrenburg, Spitz, Stein, Sturgeon, Yeagar.

I might be challenged for my frequent references to the pest control industry, but it is a significant part of our strong foundation. Had it not been for the industry, the recent scientific thrust in urban entomology would not have occurred! Also, it wasn't so long ago that within our discipline, some of our colleagues belittled those who chose to study cockroaches and termites. Fortunately, there were some who dared and they have made all of the difference.

What is now impressive is the growth of research which undergirds urban pest control. In the 1930s, there were a few individual researchers including medical and stored grain entomologists, but not institutions, dedicated to research on urban and industrial pests. In the 1940s, we began to see some universities and the USDA commit resources. The count today is at least 22 and growing:

Auburn	Kentucky
Berkeley	LSU
Clemson	Maryland
*Florida	Mississippi
USDA	Nebraska
•Gainesville	*North Carolina State
•Gulfport	*Purdue
•Ft. Lauderdale	*Riverside
Georgia	*Texas A&M
Hawaii	*VPI
K State	Washington State

Two, perhaps three of these states have identified themselves as centers of excellence in urban pest control, and that is admirable. The states indicated by an asterisk are those comprising a proposed research consortium for urban entomology. I want to indicate some of the researchers who, ten years ago, helped develop a strong position for urban entomology: Akre, Beal, Bennett, Brenner, Cochran, Gold, Koehler, LaFage, Nutting, Reiersen, Ross, Robinson, Rust, Wright, Zungoli. More and more researchers are casting off facades of self-sufficiency and are working together on research projects. This is a very positive development. The cooperation is extending also to include insecticide manufacturers that provide materials, funding and valuable counsel. A variety of projects is represented in this effort including cockroaches, subterranean termites, fleas, a number of species of ants, new insecticides, bait development, pheromones, and recently, extensive studies concerning aeroallergens. When I started preparing this talk, I had intended to discuss in some detail the current status of research in our discipline. I then discovered that that subject had been chosen as the final paper to be given by Coby Schal who is the ideal person to present it. This is just fine because it is time for me to wind down on my historical approach to the now strong foundation of urban pest control.

I do want to say something about change. Change is in vogue today and I sense that some people expect it of our discipline. Remember, though, that the initial reason for pest control has not changed since the problems in the Garden of Eden. Anyway, how limited

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•Ft. Lauderdale	*Riverside
Georgia	*Texas A&M
Hawaii	*VPI
K State	Washington State

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is our ability to influence the rate and direction of change! And that is probably not all that bad. What is changing are the images of the industry and urban entomology which undergirds it. So, be patient; time will accommodate us and progress will surely be your reward.

What is important is that we always look for ways to improve the public's understanding of urban pest control. We have several things going for us. Historically, we have been related to and sometimes intertwined with medical entomology. This is true today and it puts pest control in a rightful position of being strong contributors to human health. Currently, there is also a valid association with environmental quality through urban pest management in the home and in the workplace. The pest control industry is a business of technology and it is people-oriented. Its image is steadily improving, but public relations must be a constant concern even for those who are basic research scientists supporting the practical thrust of urban pest control. A tip of the hat goes to NPCA for its annual Legislative Day on the Hill in Washington. It is a paradox that most people abhor pests and yet are curious about them and want to know about them. There is great biodiversity to consider. We require our students to identify and know the biology of way more than 100 species of urban insects and related arthropods. What a gold mine for relating to the public!

What is so significant about urban pest control and urban entomologists' part in it is the broad base from which we operate. Look at the ingredients of it. Man's early concern with pests and vectors of disease was eventually answered by individual exterminators who, in turn, organized as associations of pest control operators. Generally, these have been and are strong and resourceful persons. Walter Ebeling said it best in the dedications of his book *Urban Entomology*. "To the pest control operator, in recognition of his contributions to health, comfort and the quality of life in the urban environment."

The research arm of urban entomology has come into its own with far reaching studies on the cutting edge of progress. The chemical industry, too, has responded to the need for controlling urban pests and has now moved forward as a strong supporter of research endeavors. Young entomologists are moving freely into urban entomology as a career and the numbers are swelling. Best of all, urban pest control is people-oriented, thus providing constant incentive to succeed in the service of others.

Together, all of these ingredients comprise urban pest control — a strong foundation. It is for you in the audience to take it from here.

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SAMPLING GERMAN COCKROACH FIELD POPULATIONS

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ABSTRACT: Accurate estimation of population size is a critical component in the evaluation of pest management tools and tactics. While urban entomology has devised an array of methods for capturing insects, there are few examples of these techniques being employed in studies to develop validated, accurate sampling methods for common urban insect pests like cockroaches, ants or termites. In our research with the German cockroach, portions of which are reviewed in this paper, we have been examining sampling techniques and population ecology with the goal of developing more precise and reliable sampling methodologies for estimating population density for the German cockroach.

KEYWORDS: spatial distribution, sampling, efficacy trials, data analysis.

INTRODUCTION

Sampling to estimate population density of a pest species is the foundation of integrated pest management (IPM). Without reliable data on the levels of pest infestation, there can be no decision generated by the various action thresholds in the management system. As a result of this significance to the operation of IPM, great volumes of research have been conducted on the basic population ecology of pest species and its application through sampling theory to develop fundamentally sound, validated sampling methods (see Binns & Nyrop 1992, Kogan & Herzog 1980, Nyrop & Binns 1991, Pedigo & Buntin 1994, Southwood 1978).

Regrettably, this sophistication in sampling design has not yet reached even the formative stages in urban entomology. A wide variety of methods have been devised for capturing cockroaches, cat fleas, termites, ants, and other urban pests, but few of these *relative* sampling methods have been analyzed for bias, accuracy, precision, etc. Further, no one -- that we are aware of -- has formally analyzed spatial dispersion *and* used sampling theories to design reliable sampling methodologies for use with any of these techniques for capturing insects.

At present, the dominant use for sampling in urban entomology relates to attempts at estimating population size in association with efficacy studies for various pest management tools and technologies (insecticides, devices, etc.). By extrapolating from the number of trials at Purdue and Auburn in the past three years, we estimate that manufacturers spend between \$300,000 and \$500,000 annually for research evaluating the effectiveness of various sprays, baits, and devices for the German cockroach alone. When factoring in similar research with other pest species in urban environments (various ants, the cat flea, and subterranean termites), nearly \$1,000,000 is likely invested annually in efficacy research. In our opinion (which is bolstered by the critical analyses presented by Taylor in his 1987 "Forum" article in *Environ. Entomol.*), most of this data is suspect as unreliable because of a lack of appreciation for fundamental sampling theory that under girds the precise, reliable estimation of population density.

In recognition of the significance of this problem, our research programs at Purdue and Auburn have joined forces to develop valid sampling methods for the German cockroach. We are working on three related objectives: 1) study population ecology, especially spatial dispersion, of German cockroaches in the field; 2) apply this knowledge to improve sampling procedures and data analysis in efficacy trials; and, 3) transfer these developments to PCOs in the form of validated sampling and monitoring programs for German cockroach IPM. In a previous presentation to this conference (Appel & Reid, 1992), we reported on our progress with the first objective. Today we will consider the progress towards satisfying the second objective.

BASICS OF POPULATION ECOLOGY

Spatial dispersion, and its integration with sampling theory (e.g., Ruesink 1980), is significant to valid estimation of population size because issues like sample size, the confidence in estimates, or sequential sampling schemes are dependent on the distribution patterns of the species being studied. We have already detailed our analyses of spatial dispersion in German cockroach field populations (Appel & Reid 1992). Since 1992 we have taken efforts to secure further data to more firmly establish our analysis of spatial dispersion. These efforts are summarized in Figure 1.

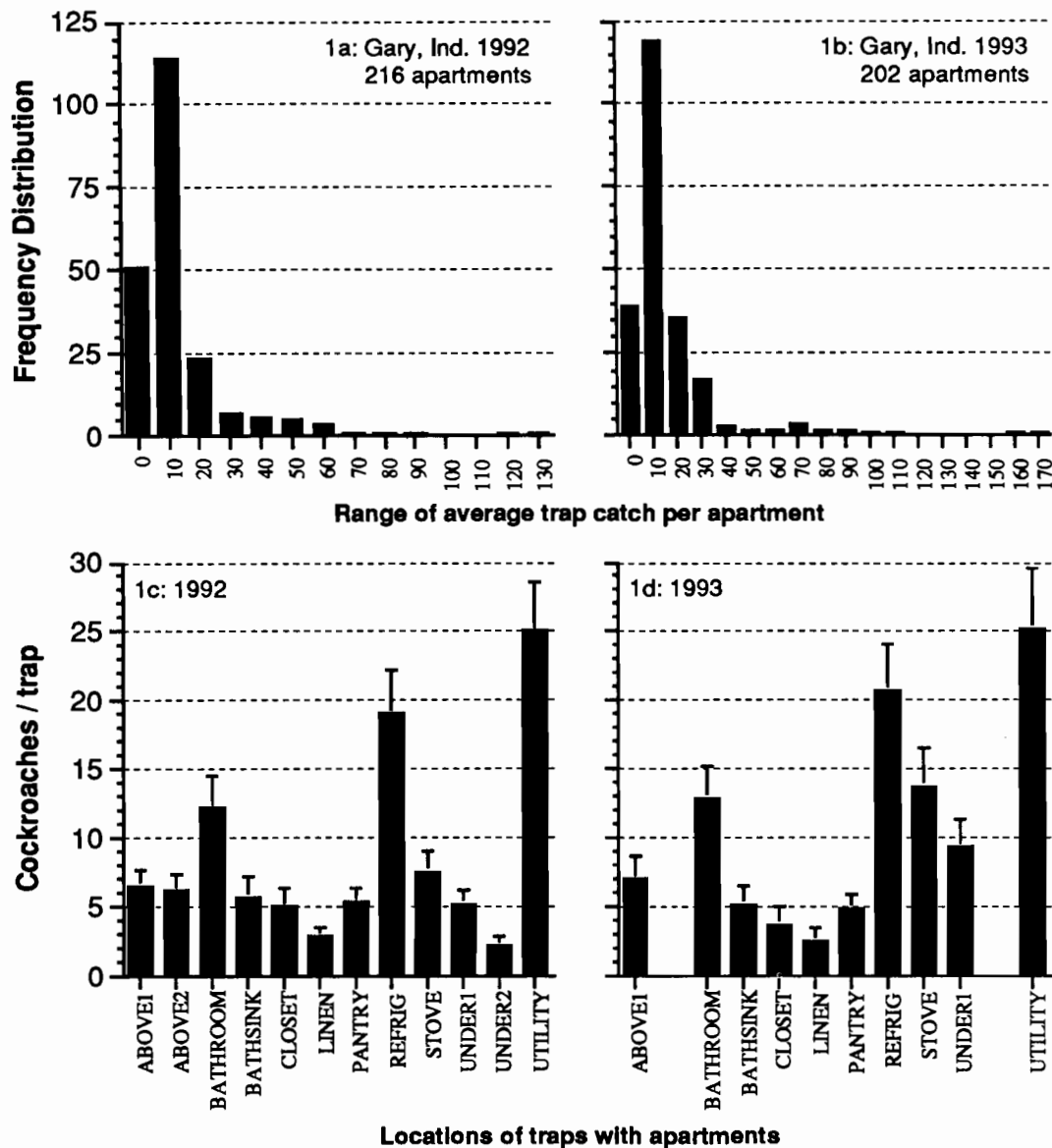


FIGURE 1: Constancy in spatial dispersion patterns of German cockroach populations among and within urban apartments. *Figures 1a&b:* the frequency distribution for the number of cockroaches trapped per trap ($n \leq 12$ traps) per apartment ($n > 200$ apts.) in the Ivanhoe Gardens complex (total of 317 apts.). *Figures 1c&d:* the distribution patterns within kitchen and bathroom areas of these same apartments.

These patterns of spatial dispersion, both among apartments (Fig. 1a&b) and within apartments (Fig. 1c&d), have proven to be highly consistent. We (unpubl. data) have described substantially identical patterns from data taken with different sampling methods, in different locations, over several years, by various researchers. The consistency found in these data provide evidence to support concluding that these spatial dispersion patterns *are* species specific and, thus, will probably arise whenever any population of German cockroach is sampled by any means.

The significant feature in these patterns is the highly skewed, non-normal distribution of individuals in space (i.e., clumped distributions) which carries with it extreme variance. This variance is attributable to two facts: there will always be a small number of apartments which are heavily infested (1a&b) and within apartments the variance is proportional to the mean (i.e., heavily infested trap sites like the refrigerator or utilities have high variance (1c&d) between apartments).

In our opinion, most problems in current sampling programs deployed for efficacy studies are related to extreme variability in the resulting efficacy data. Accordingly, our thoughts regarding sampling designs in cockroach efficacy trials are largely a response to the need for either minimizing or partitioning this variance in an attempt to obtain a clearer interpretation of the true efficacy of the product(s) being evaluated.

DESIGNING SAMPLING PROGRAMS FOR EFFICACY TRIALS

Our sampling programs accept that heterogeneous distribution patterns cause the extreme variance in data sets from efficacy trials, and attempt to minimize the confounding effects this variance has in the analysis of product performance. We operate our partitioning of variance at two levels: 1) when we select replicate test populations (i.e., apartments) and 2) the number and location of sample sites (i.e., trap placement).

Selecting apartments for inclusion in the efficacy trial

As the overall distribution of mean trap catch density among apartments is highly skewed (Fig. 1a&b), and thus not described by a normal distribution, neither will a randomly selected sample of apartments assigned to a particular treatment be normally distributed. As a result, the apartments sampled for density before treatment in an efficacy trial will invariably be plagued with severe non-normality and high variance. We have adopted two, related procedures for addressing this problem: 1) exclusion of heavily infested apartments and 2) partitioning efficacy data according to the levels of infestation before treatment.

Excluding heavily infested apartments from efficacy data -- Nearly all efficacy trials employ a "lower exclusion limit" for inclusion of apartments for the observation of efficacy: of course, one must first have cockroaches in an apartment in order to determine whether a product will control them! In the Purdue research programs, this states that for an apartment to be considered as a "test" apartment the trap catch before treatment must average a minimum of 2.0 cockroaches per trap ($n \leq 12$ traps).

In an effort to lessen the variance attributable to the small number of heavily infested apartments (see Fig. 1a&b), we employ an "upper exclusion limit" wherein apartments whose average trap catch before treatment exceeds a certain value are blocked from inclusion in the replicate complement observed when defining efficacy. In the Purdue research programs this procedure limits assignment to "test" groups those apartments

where average trap catch before treatment ranges from a low of 2.0 cockroaches per trap to a high of 20.0 cockroaches per trap. There are a number of justifications for adopting this practice: 1) excluding apartments with extremely high densities results in data on trap catch density before treatment which is nearly normally distributed, with greatly reduced variance; 2) performance of many materials is likely to be unsatisfactory under such extreme conditions; 3) the more uniform replicate test populations should yield more consistent (i.e., interpretable) results.

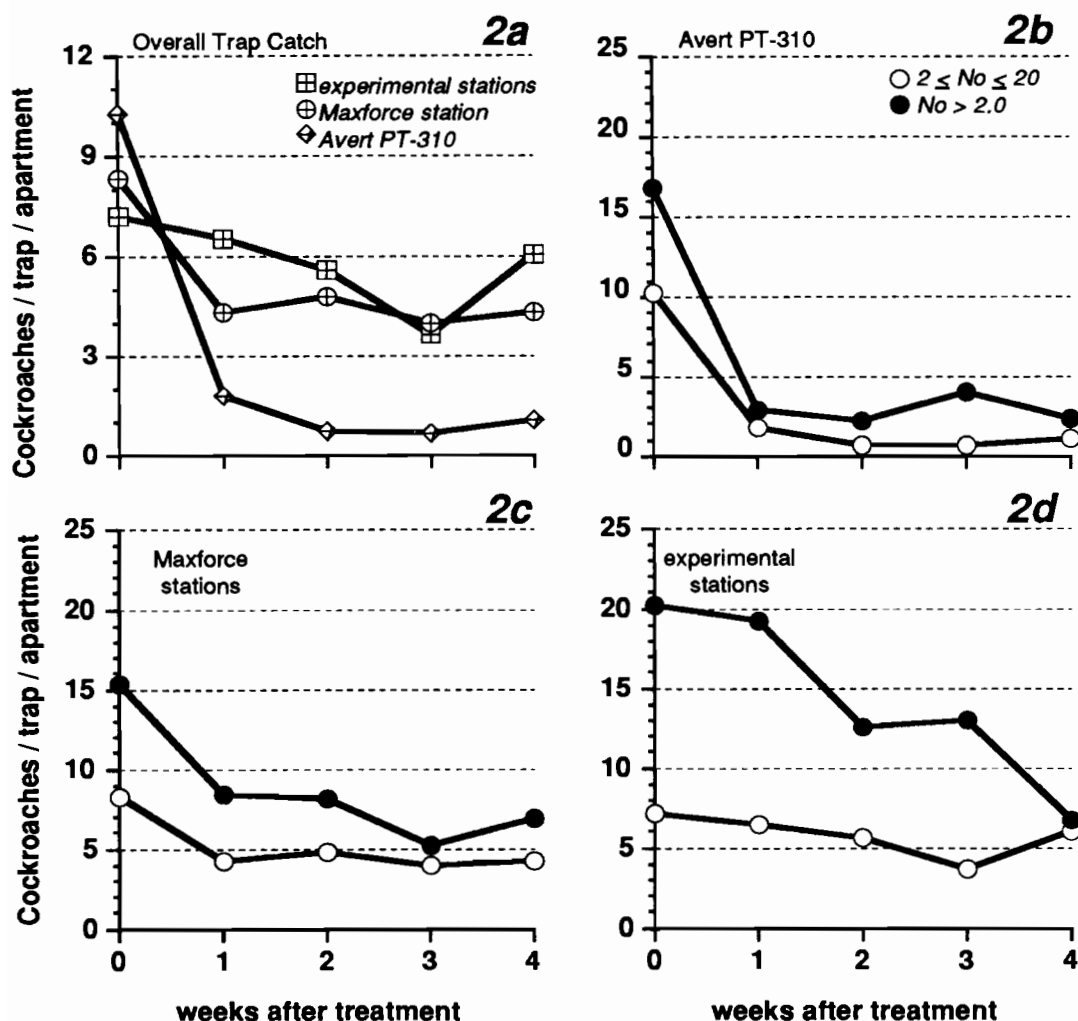


FIGURE 2: Efficacy trials from Purdue (1992) on the performance of three insecticidal cockroach baits, illustrating the impact highly infested apartments may have on interpretations of product performance. Fig. 2a compares efficacy among the three products. Fig. 2 b, c, & d compare performance, for each product, if heavily infested apartments are either included (trap catch before treatment, $N_0 \geq 2.0$) or excluded ($2 \leq N_0 \leq 20$) from the data sets.

Consequences of the upper exclusion limit on efficacy interpretations are graphically displayed in Fig. 2. These graphs present results from three bait products tested by Purdue in the summer of 1992; the data set is considered throughout this paper and was selected as an example because efficacy of the baits range from highly effective [Avert] to ineffective [experimental bait

station]. The bait performance is contrasted between the data set when only the lower exclusion limit is invoked and when heavily infested apartments are excluded. For two of the three products (Fig. 2b&c) there was no substantial difference in the description of efficacy due to exclusion of heavily infested apartments, but there were significant differences in the performance for the experimental bait stations (Fig. 2d) attributable to the exclusion of those apartments with extreme cockroach populations.

TABLE 1 -- Benefit of excluding highly infested apartments in efficacy trials.

<u>Parameter</u>	<u>Mean trap catch before treatment</u>	
	<u>≥ 2.0 roaches</u>	<u>$2.0 < \text{roaches} \leq 20.0$</u>
Normality ^a	2 of 31	13 of 31
Var. Equality ^b	1 of 7	6 of 7
Coeff. Var. ^c	@ 0wk	103.6
	@ 1wk	162.6
	@ 2wk	182.1
	@ 3wk	243.0
	@ 4wk	284.6
		59.4
		85.1
		91.3
		89.6
		124.1

^a - Shapiro-Wilks W-test; data refer to the number of cells which were found to be normally distributed at $\alpha = 0.05$.

^b - Bartlett's test for unequal sample size; data refer to the number of one-way ANOVAs within time for which variance equality was satisfied at $\alpha = 0.05$.

^c - From a one-way ANOVA among treatments within each time period, the coefficient of variation (%) for the contrasting data sets.

In Table 1 we contrast a variety of statistical indices from the analysis of this efficacy data with and without the exclusion of apartments with high cockroach populations. Not only is compliance with the normality and variance equality assumptions in ANOVA enhanced by exclusion of heavily infested apartments, but the coefficients of variation are greatly reduced for the ANOVAs conducted within times among the treatments. On the whole, excluding heavily infested apartments improves the ability of our analyses to isolate relative differences in product performance. The outcome with this data is not exceptional, as our experience in the past few years have found this to the normal outcome.

Partitioning data by density -- Partitioning efficacy data according to densities before treatment is simply an extension of the example above where heavily infested apartments are excluded (i.e., partitioned) from the overall data. By partitioning all apartments whose infestation exceed the lower exclusion limit into two or more density groups, we create a scenario for determining whether a product's performance may be differentiated according to the severity of the infestation. In Fig. 3 we present examples of partitioned efficacy data for density groupings of **low** (mean trap catch before treatment [No]: $2.0 \leq \text{No} \leq 10.0$), **high** ($10.0 < \text{No} \leq 20.0$), and **extreme** ($\text{No} > 20.0$) infestations. From the graphs it can be seen that while one bait performed equally well under all three density groupings (Fig. 3b),

the other two baits (Fig. 3c & 3d) display significantly differing performance according to the initial infestation severity; these two baits performed better (greater reductions in trap catch) in apartments with extreme infestations.

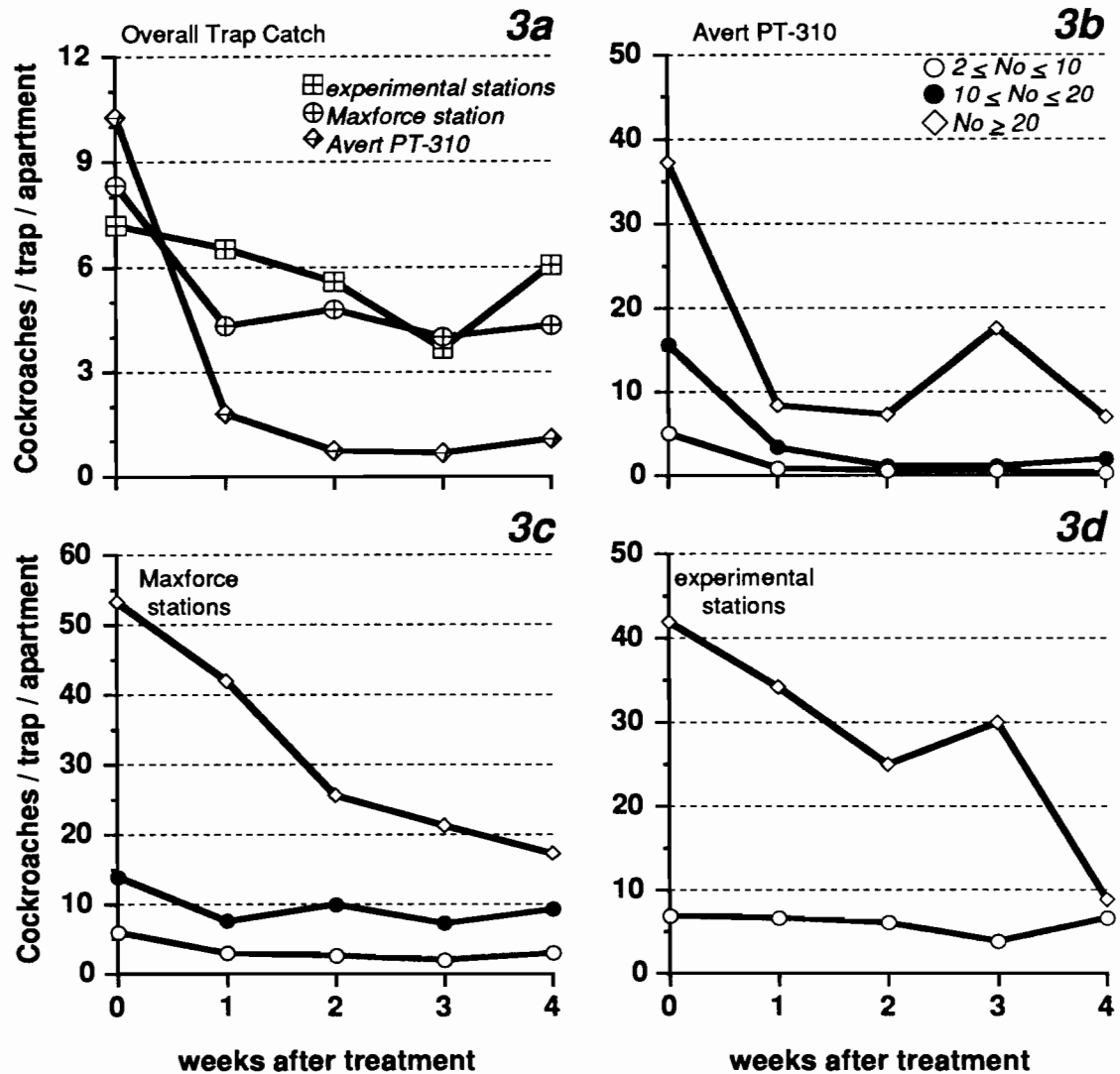


FIGURE 3: Efficacy trials from Purdue (1992) on cockroach baits, illustrating the impact of density partitioning on the interpretations of product performance. Fig. 2a compares efficacy among the three products. Fig. 2 b, c, & d compare performance, for each product, when trap catch before treatment is used to sort apartments into three (3) groups: low infestation (trap catch before treatment [No] ranged from $2.0 \leq No \leq 10.0$), high infestation ($10.0 \leq No \leq 20.0$), and extremely infested ($No > 20$).

The partitioning of efficacy data according to infestation severity will benefit product development research by revealing subtle patterns in performance which would otherwise go undetected. The partitioned data sets can be analyzed separately, or initial trap catch density can be included as a co-variate in analysis of covariance.

Selecting trap sites within apartments

Any discussion of where to locate traps within apartments must begin with a consideration of the number of traps required for our population estimates to have reasonable precision. Once we know the number of samples required, we should locate traps at a diverse series of sites so that we may sample the cockroach population from a variety of microhabitats. Placing all traps at or near the prime harborage sites (e.g., refrigerator, stove [see Fig. 1c&d]), which has been a common practice of many researchers for years, does yield high numbers of cockroaches for determining the performance of product, *but this practice introduces unacceptable bias* in our estimates of population density.

Number of samples needed to precisely estimate density -- One of the more useful applications we have made as a results of having clearly defined the patterns of spatial dispersion for German cockroaches is the determination of sample size necessary to estimate population density. In Fig. 4 we present a graph depicting Taylor's (1978) regression of variance over mean density for data on over 200 apartments in one of the complexes sampled by researchers at Purdue in the summer of 1992.

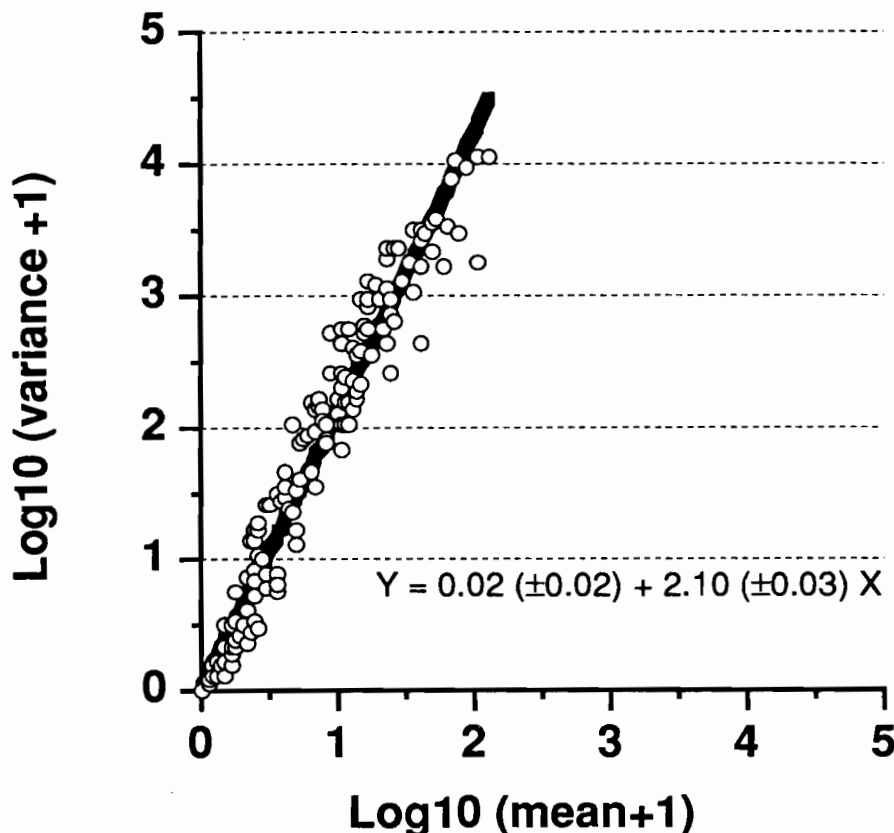


FIGURE 4: Applying Taylor's (1978) log-log regression of variance on mean sample density from trap catch data taken in 216 apartments at the Ivanhoe Gardens complex in Gary, Ind. during the summer of 1992 (see Fig. 1c). This regression equation was both significant ($F = 6007.2$; $P < 0.0001$) and predictive ($R^2 = 96.5\%$).

Ruesink (1980) presents an equation to determine sample size that relies on parameters generated by this regression (Fig. 4). By taking this equation, varying the level of confidence we are willing to accept in population estimates, and varying the number of cockroaches (or a change in density) we wish to detect, we can generate the following table of sample sizes (number of traps per apartment) *theoretically* required for acceptably confident estimates of density.

TABLE 2 -- Sample size (No. traps / apartment) determinations.^a

To detect N cockroaches ^b	with a confidence ^c	required # traps / apt
25	0.05	570
	0.10	143
	0.25	23
50	0.05	610
	0.10	152
	0.25	24
100	0.05	652
	0.10	163
	0.25	26

^a - parameters from regression (Fig. 4) are used in Ruesink's (1980) equation: the slope = 2.10 ± 0.03 ; the intercept = $\text{antilog}(0.02 \pm 0.02)$.

^b - If trap catch equaled 100 cockroaches per apartment before treatment, this equates to ascertaining whether trap catch has been decreased by a given number of cockroaches; e.g., 25 fewer cockroaches = 25% control; 50 fewer = 50% control; 100 fewer = 100% control, or elimination!

^c - this denotes variance of $\pm 5\%$ of the mean value (= 0.05), $\pm 10\%$ of the mean value (= 0.10), or $\pm 25\%$ of the mean value (= 0.25).

We have repeated these analyses with other data sets, from both Purdue and Auburn, and generate equivalent regressions of the variance in trap catch within apartments over the mean trap catch per apartment. Thus, this exercise of determining sample size invariably yields equivalent results, regardless of the sampling method(s) used (including visual counts), housing design (e.g., duplex or row-houses), or geography. These results demonstrate that, given the heterogeneous distribution of cockroaches within apartments, a great number of samples are required for precise estimation of density! Even if we can accept only a 25% level of confidence in our estimate we must use more than 20 traps per apartment.

In the sampling designs currently used at Purdue and Auburn we only use 10 to 12 traps per apartment. While this is fewer traps than the *theory* behind Ruesink's equation indicates is required, this sampling is more intensive than typical of most efficacy trials. Clearly, German cockroach efficacy trials that rely on traps placed at 3 sites (e.g., refrigerator, stove, and under sink) to infer on the trends in population size are NOT utilizing a sampling program that is intensive enough to result in even a modest level of confidence in their results.

Evaluating efficacy by trap sites -- We know that the spatial dispersion of German cockroaches is clumped (or centered on) certain, highly favorable microhabitats (e.g., utility or refrigerator [see Fig. 1c&d]). In the past, when we selected locations for trap placement, we targeted these "focus" areas (after Akers & Robinson 1981). We now know that a better sampling plan considers a variety of sites that represent both optimal and marginal microhabitats.

By virtue of the large numbers of traps required for precise estimation of population size, we distribute traps over a range of locations within the apartment. In a procedure akin to the partitioning of apartments by density, we can also utilize the various trap locations for defining the efficacy of pest management tools from specific habitats (e.g., how well do baits eliminate cockroaches from the refrigerator?).

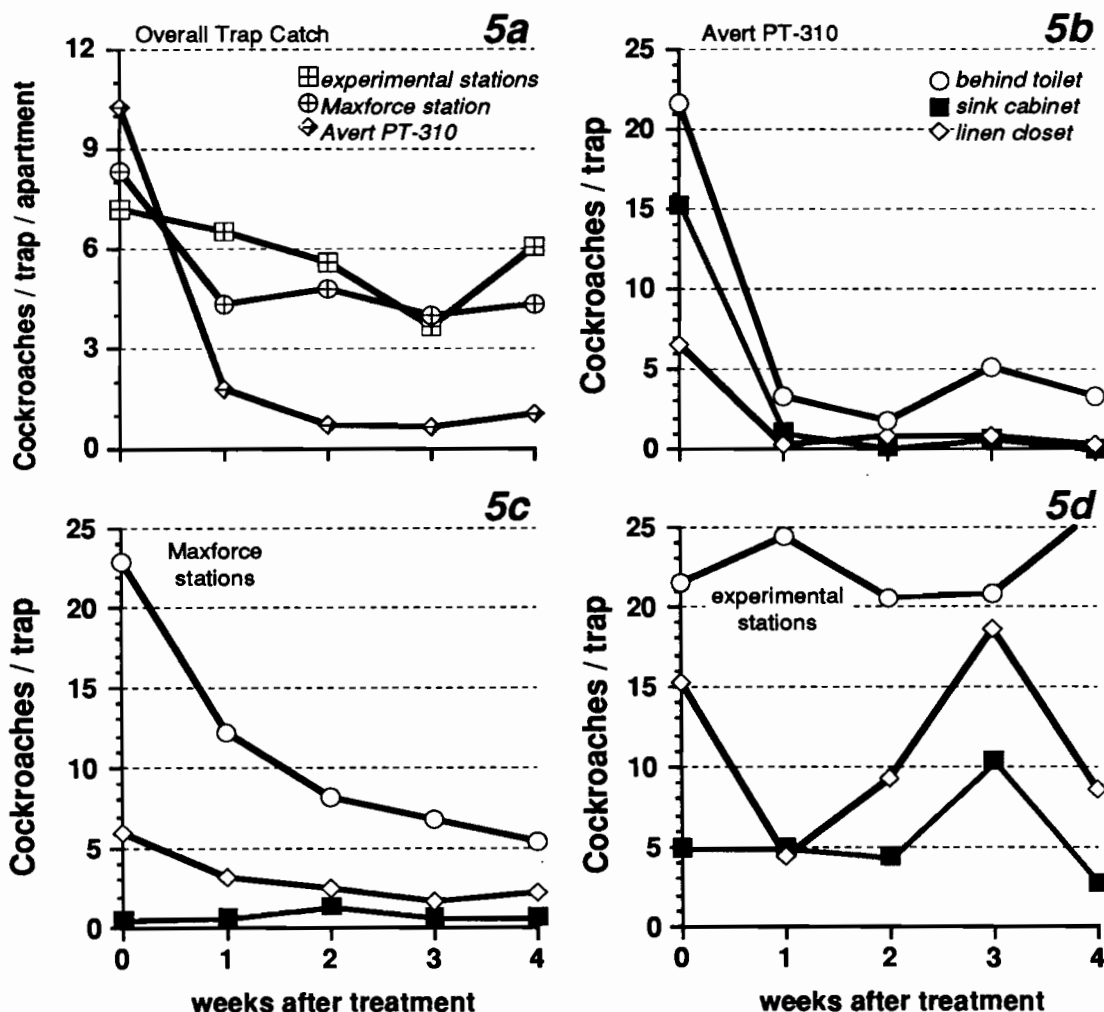


FIGURE 5: Efficacy trials from Purdue (1992) on cockroach baits, comparing efficacy at different sites within and adjoining the bathroom area in apartments. Fig. 5a plots efficacy for three baits as determined from all of the traps ($n \leq 12$) in the apartment. The remaining plots (Fig. 5b, c, & d) describe efficacy, for each product, at three traps situated in or adjoining the bathroom; these sites present a gradient of density for efficacy evaluations.

In Fig. 5 we consider a bathroom area and its trap sites, to exemplify how contrasts of the reductions in trap catch after treatment between sites can be beneficial. In the bathroom area, we place traps at a "focus" area (where the greatest number of cockroaches are captured, 'behind toilet') and at two adjoining, marginal sites (i.e., the "sink cabinet" and "linen closet" traps). By looking at the bait's efficacy in this manner we can formulate hypotheses on the bait's impact on the population centered about the water source(s) in the bathroom. With Avert (Fig. 5b) we observe abrupt and dramatic reductions in trap catch at all three sites, although the toilet trap continues to catch low numbers of cockroaches during the following weeks. With Maxforce bait stations (Fig. 5c) the reductions in trap catch at the toilet are gradual, while the traps at the other, marginal sites are little affected. Lastly, experimental bait stations (Fig. 5d) failed to impact trap catch at the toilet, and thus trap catch at the outlying, marginal sites fluctuate over time.

This example developed on the bathroom area could just as easily have been developed from the kitchen, or even been composed over the entire area sampled. The basic idea is that -- as with differential infestation at the level of the replicate apartment -- differing population sizes are associated with the various locations within the apartment. Some areas, like the utility or refrigerator, are likely breeding foci dominated by gravid females and young nymphs. Other areas, like cabinets or closets, are [at best] ancillary harborage or merely foraging areas that are dominated by the more mobile males and large nymphs, or non-gravid females in search of resources. Within these diverse microhabitats one would expect that certain products, especially insecticidal baits, would vary in their performance.

This example is very preliminary and we have not finalized these ideas for utilizing individual traps sites, and comparisons among trap sites, to examine product performance. However, we are convinced that this general approach will be an integral component in our model system for determining product performance against field populations of the German cockroach.

IMPROVING THE DESIGN OF SAMPLING PROGRAMS

We have reached several interim conclusions for steps which can be taken to improve the design of sampling programs employed in the conduct of efficacy trials with German cockroaches. With respect to "selecting" groups of replicate apartments for the treatments being evaluated, these considerations are 1) to ensure random selection of apartments, 2) exclude relatively heavily infested apartments from the compliment of apartments being observed to describe efficacy, and 3) utilize initial infestation density as a co-variate by means of partitioning.

With respect to "selecting" sampling sites within apartments, the principle considerations are that 1) we *must* use a large number of traps within each apartment, certainly no fewer than 10 in the kitchen area, and in so doing 2) we should sample from a diverse range of microhabitats and 3) then examine efficacy trends between individual (or grouped) trap sites, which can be a great aid to attempts at interpreting equivocal results (e.g., why one treatment does not work).

STATISTICAL ANALYSIS OF FIELD EFFICACY DATA

Once apartments and trap locations are selected and the experiment has been conducted, the data can be analyzed using several approaches. Two major comparisons among treatments are made: those within a time period between treatments, and those among time periods for a given treatment. Some conventional analytical methods employed are briefly reviewed below.

Traditional approaches to analysis of efficacy data

For comparisons within a time period both parametric and nonparametric types of analysis have been used. With parametric analyses, data are transformed to meet assumptions of additivity of treatment and environmental effects, equivalence of variance, and random, independent, and normally distributed experimental error. Either trap catch or percentage reductions are compared with analysis of variance (ANOVA) and a multiple range test. Nonparametric tests do not assume additivity, normality, or equal variance, but are typically less powerful than parametric tests.

For comparisons among time periods, regression has been used to relate the change in a variable with time. For linear regression, mean trap catch must be transformed to linearize the otherwise curvilinear relationship. Often a simple $\log_{10}(\text{mean} + 1)$ transformation will be sufficient, but only if the means do not increase too rapidly towards the end of the experiment. The quadratic regression:

$$\text{Trap catch} = m_1 \cdot \text{Time} + m_2 \cdot \text{Time}^2 + b \quad [\text{Eq. 1}]$$

where b is the intercept (initial trap catch) and m_1 and m_2 are the regression coefficients for time and time squared, respectively. The m_1 coefficient characterizes the initial change in the population after treatment, typically this is a negative number if the treatment reduced trap catch at all. The m_2 coefficient describes the rate of population increase and is usually a positive number.

An approach that combines comparisons of treatments within and among time periods is the split-plot-in-time ANOVA. This design has the same assumptions of ANOVA, but will remove variation due to apartments, dates, and the interaction of the two. One mean is generated for each treatment and the analysis separates treatment effects. Unfortunately, this type of analysis gives no information on time courses such as length of effectiveness, rates of decline, or speed of action.

A unified approach for analyzing efficacy data

When conducting an efficacy study, there are five basic questions for which we desire to obtain answers:

- | | |
|---|--|
| 1 Did the treatment work? | 2 How fast did the treatment work? |
| 3 How well did the treatment work? | 4 How long did the treatment remain effective? |
| 5 Is one treatment "better" than another? | |

All of the analytical designs discussed above are limited because they can not simultaneously answer all five of these questions in an easy and unbiased manner. In addition, interpretations of product efficacy should be based on cockroach biology and biological principles; this simply is not possible with the conventional approaches to data analysis.

We have started to develop a biologically based model of cockroach population growth that is linked to insecticide degradation and insecticide induced mortality. At this time immigration and emigration are not included in the model, but interapartment movement is relatively insignificant (Owens & Bennett, 1982; Runstrom & Bennett, 1984; Barcay et al., 1991) and should not greatly affect results. Together with Dr. T. P. Mack at Auburn University, we have developed a simple, biologically-based model that predicts cockroach population size from effective insecticide concentrations and species specific growth rates.

The difference equation model:

$$C_{t+1} = -a_1 * C_t + C_t \quad [\text{Eq. 2}]$$

$$N_{t+1} = a_2 * N_t - a_3 * C_t * N_t + N_t \quad [\text{Eq. 3}]$$

relates the change population at a future time (N_{t+1}) to the starting population (N_t), population growth ($a_2 * N_t$), insecticide concentration (C) or availability, the effect of an insecticide on the population (i.e., insecticide induced mortality). The change in insecticide concentration at a future time (C_{t+1}) is related to initial insecticide concentration (C_t) and the change in insecticide concentration over time ($-a_1 * C_t$). Change in insecticide concentration over time can be based on experimental studies (e.g., Braness & Bennett 1991). In this model, change in insecticide concentration could also represent depletion of bait from a station, repellency, or even insecticide resistance.

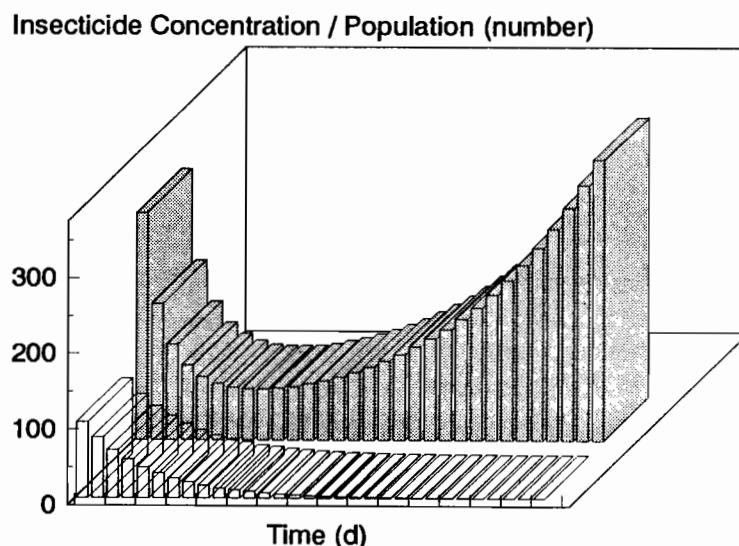


FIGURE 6: The relationship between degradation of insecticidal effects (open bars, in foreground) and population size (solid bars, in background), as modeled by the difference equation [Eq. 2&3] proposed for analysis of efficacy. This function (i.e., initial decline and subsequent recovery of population size) following an insecticide treatment is encountered a surprising number of times in actual field data on insecticidal spray or bait performance!

Assuming that the concentration of insecticide at time t is 100% and that there is a daily 50% loss of the deposit, by day 18 there is >2% of the initial concentration (Fig. 6). Starting with a population of 300 cockroaches and assuming a population growth rate of 10%, combining the population equation [Eq. 3] with the insecticide degradation equation [Eq. 2] results in curvilinear rapid decline, minimum population, and a rate of gradual population growth (Fig. 6). In this model the minimum population was 67 individuals, a 78% reduction in initial population. Minimum population corresponds with day 9 after treatment and an insecticide concentration of 17%. Although the parameter estimates of both model equations can be adjusted, the basic pattern of population change over time is similar.

A biologically-based model *will answer the five questions* posed by the objectives of an insecticide efficacy study. If the slope for the regression of trap catch over time is not significant then a treatment did not affect that population; i.e., the treatment did not work. Appel (1990, 1992) described the effect of various bait treatments using a regression model and found that while untreated control apartments did not have significant regressions, effective treatments had significant regressions with negative slope coefficients. Using quadratic regression or the difference equation model, how well a treatment worked can be determined by solving for the minimum trap catch, or the point of inflection for the function. This point describes the maximum population reduction achieved by the treatment. How fast a treatment worked can be addressed by the magnitude of the negative m_1 regression slope of a quadratic model. A larger negative slope indicates a more rapid decline in population. How long a treatment remained effective is a function of the magnitude of the m_2 coefficient of a quadratic regression. By using regression, treatments can be compared in more than one way. Speed of action, minimum population size, and length of effectiveness can all be compared using a single analysis. We believe that this unified, unbiased analysis based on dynamic models will yield significant improvement in the interpretation of insecticide efficacy data from field trials with the German cockroach.

EXPERIMENTAL DESIGN

Once the protocols for trap placement, sampling, and statistical analysis are set, the various experimental treatments need to be decided upon. We are too often faced with requests for treatments that are of unrelated formulations, active ingredients, or treatment strategies. In designing comparative studies, not only useful, but fair treatments should be examined. For example, is it fair or reasonable to compare a slow-acting bait with a fast knock down spray? In essence this is setting up a straw-man; i.e., we know (or can reasonable predict) the results before the experiment is conducted. Choice of formulation can also make treatment comparisons "unfair". Because substrates affect insecticide residues, comparing the length of activity between an EC and a containerized bait is almost meaningless; of course the bait will last longer, it is protected. Even different formulations of the same active ingredient have different degradation rates. These

degradation rates determine much of the efficacy of a treatment. Again, treatments can be selected to give particular results based on formulation alone. Even fair treatment comparisons can be affected by the level of physiological resistance by a population to one or more of the active ingredients. If a particular active ingredient is used against a known resistant population, the experiment is biased against that active ingredient.

With the expense and difficulty of conducting good field efficacy trials, treatments should be selected to give more than just minimal information. For example, more than one concentration of an active ingredient or more than one formulation of the same amount of active ingredient should be included in an experiment. Several treatments of different numbers of bait stations should also be considered. More information that can help cooperators can be obtained if treatments groups contain *a gradient of the variable(s)* in question. Gradients help to diagnose problems like not enough insecticide, optimal formulation, or number of bait stations or placements (see Appel 1992) for best performance. Using gradients will help to address “why” questions about performance rather than the more simplistic “what happened” question that is answered by most experimental designs.

Almost all insecticide efficacy studies in field crops utilize untreated control plots. Why? Controls allow us to factor out the effects of the environment, epizootics, etc. from the effects of the treatments. How do we know that the reductions we see are a result of the treatment and not a natural decline? A control tells us! It is understandable to think that everyone in every infested apartment wants to be treated. However, this is not always the case. In our studies in Opelika, AL, nearly 10% of residents do not want any insecticide used in their apartments (unpubl. data). These individuals will agree to let us place sticky traps and take the cockroaches away. There do not appear to be any differences in cockroach populations between apartments whose residents refuse insecticide treatment and those who agree to treatment (unpubl. data). Insecticide resistance levels are similar, as are the distribution pattern of the populations within kitchens (unpubl. data).

Most field performance experiments are conducted for 12 weeks. In a recent industry survey, however, approximately 75% of the PCO respondents reported that they treated commercial accounts at monthly intervals. If one month is the relevant time period for the user population, how can we justify increasing the length of an efficacy experiment? A 12 week label claim has obvious marketing appeal, but few of the treatments we have evaluated [other than some slow-acting baits, growth regulators, and biologicals] have better efficacy at 8 or 12 weeks than at 4 weeks (unpubl. data). As outline above, populations can be modeled once the rate of decline immediately after treatment and the minimum population size have been determined. The key to population size is degradation, removal, or differential effectiveness of the insecticide. These factors can be determined in laboratory or simulated field experiments.

META-ANALYSIS

A company will usually contract with several researchers or consultants to conduct similar field trials. The results of these studies are often expressed differently and analyzed differently. How can the company, or researchers themselves, looking for general trends draw conclusions from these different studies? Meta-analysis is a family of statistical techniques that provides the ability to describe and summarize the results of several independent studies (Hedges & Olkin 1985, Mullen 1989, Mullen & Rosenthal 1985). The results of different studies are used as data in a further analysis. Meta-analysis is based on nonparametric methods and, therefore, indirect evidence (e.g., survey results or subjective impressions) can be combined with direct evidence (e.g., trap catch or visual counts).

Meta-analysis provides an unbiased method to combine the results of separate studies, even studies with different numbers of replicates, different sampling methods, and even some different treatments. An overall level of effectiveness can be calculated. Meta-analysis is used in psychological studies, biomedical research, particularly drug studies, and sociological studies. We believe that the powerful methods of this analytical tool can be used effectively to summarize the results of field trials of insecticides.

THE FUTURE OF FIELD EFFICACY TRIALS: AS WE SEE IT!

Because of the need for more accurate sample data, we believe that more traps will be used in each sampled apartment but, with proper apartment selection, fewer apartments will be used for each treatment. The duration of field trials will be shortened with an emphasis on population modeling. Sequential sampling will probably be adopted and field trials will be terminated after the minimum population has been determined. Hopefully, there will be more studies comparing similar treatments and fewer "unfair" comparisons. Treatments will include gradients to help determine optimal concentrations or number of bait station placements. We also envision the use of meta-analysis as a way to combine study results and determine overall treatment effects.

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TERMITE BAITS IN THEORY AND PRACTICE

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ABSTRACT: The development of successful strategies for the control of subterranean termites by baits requires an understanding of the basic biology of these pest species. But because of their seemingly amorphous nests and their secretive food collecting habits, and the inability to recognize individual termites in the field, very little is understood about the social organization, reproductive dynamics, search behavior, and food selection of *Reticulitermes* and other pest species. The theory behind the development of pesticidal baits to control termites is based upon a simplistic model of the organization of an ant colony. However, this model may in fact have limited application to termites. The structure of subterranean termites and their mechanisms of social integration may either impede control by baits or offer biological properties that can easily be exploited.

RETICULITERMES; BAITS; FORAGING BEHAVIOR; CONTROL

INTRODUCTION

Imagine a termite colony that pierces the sky with its height and rivals an elephant in volume. Prominent, statuesque and impressive against the horizon, it is part of a

Manhattan-like skyline of termite mud and saliva. Foraging termites scour the surrounding area and collect anything bearing cellulose that can be degraded to mulch the mushrooms on which the termite colony thrives. Taking a pick-ax and your best shot, you open the concrete-like exterior of the nest and chip away to find a royal cell housing the queen and king, and nest chambers full of workers.

Now imagine that you have to control such a conspicuous colonial beast. What a simple task. You could bulldoze, dynamite, or directly apply termiticide. When you return weeks later, you *know* your pest management strategy was successful. You can *see* the colony is gone. Eradication guaranteed. No call backs.

Unfortunately this is *not* the termite we encounter most often in the U.S. It is an African mound-building termite, *Macrotermes*. Our own subterranean termites, *Reticulitermes*, are very different animals. These termites do not build nests that cast shadows in the sun; in fact, you can't see them at all until you've found the damage they cause. They are secretive; without the termites telling you where they are by their tube construction or feeding, you have to blindly probe beneath the soil surface with wood stakes to find them. And there is no promise that your detective work will be successful. In contrast to the central, clearly identifiable mound of the African *Macrotermes*, subterranean termites appear amorphous and strongly decentralized in their base of operations. Like the giant fungi of the Northwest that seem to go on and on, mile after mile, the same individual subterranean termite colony - if it can correctly be called a colony - may span large areas. And in sharp contrast to many species of termites, there is frequently no single pair of reproductives. In these subterranean termites replacement (neotenic) reproductives may number in hundreds in a group. Mercury dropped on the floor fragments into a hundred globules of different size; some globules may coalesce and then separate again. Perhaps this is an apt analogy for the dispersed colony organization

and reproduction of *Reticulitermes*, but little is known about the ecology of these termites. Modern control methods capitalize on knowledge of a pest's biology. A major impediment to making advances in the control of subterranean termites has been a lack of such knowledge. Afterall, you can't *see* what you are trying to control.

In our research we have tried to understand the structure and function of a termite colony and the communication systems that integrate colony activities. We have also studied the biology of ants, another important and diverse group of social insects that can serve as models to understand termite biology. The temperate zone subterranean termites and tropical rain forest species we have worked with have important similarities and differences; allowing useful comparisons among species. Such comparisons have led to new insights into termite behavior, ecology, *and* control. In this paper we will describe how an understanding of basic termite biology is critically important to devising and implementing new control technologies. Our focus will be on what appears to be a most promising strategy: baiting.

TERMITE CONTROL: YESTERDAY, TODAY, AND TOMORROW

Assemble any group of termite control experts and you will spontaneously have a memorial service for chlordane. As a protective soil drench it provided a durable, toxic barrier that afforded unparalleled control. Alas, it is gone, and we must accept its passing. But the comparative performance of its substitute soil drench termiticides will always cause us to conjure up memories of just how well the silver bullet of termiticides worked. While such nostalgia keeps many of us longing for the 'good old days', we must turn our attention to alternatives.

Right now we seem to be in a holding pattern. A number of soil drench termiticides are available as replacements for chlordane, and there are new application techniques. There are technologies for protecting wood with preservatives or protecting structures with devices such as physical barriers or shields. And there are new approaches on the horizon that seem promising enough but are nevertheless out of reach. One of these technologies is now within grasp: baiting.

The Concept of Bait Control

Using baits to control termites is by no means a new idea, and it is simple in concept. Pest species of insects need to feed, so the addition of a pesticide to a food material will give them a dose of toxicant when it finds and feeds on a pesticide-laced bait. For social insect pests such as ants and termites baits are seemingly the ideal way to exploit the species' biology to gain effective control. Ants and termites live in potentially very large colonies in which a proportion of workers in the colony leave the nest to search for food. If these scouts find a food source they recruit other colony members to help collect it. If the food source is preferred, a colony may even shift from using other food sources to collect the 'best' food. In this case the 'best' food, the bait, also contains a pesticide. Ideally, workers in a colony of social insects share food, so pesticide-containing food may be distributed within a colony. Individuals that never leave the nest to contact the food may be killed indirectly by receiving toxic mouthfuls from foragers. Over time, the colony poisons itself.

The concept of using baits containing toxic substances has roots that extend deep in the history of control of pest species of social insects. Sugar solutions laced with thallium sulphate or arsenical compounds were used in ant control centuries ago, but modern versions of these baits are no longer registered in the U.S. Such prototype baits have been

replaced by a wide variety of newer formulations containing pesticides that are lower in toxicity to mammals and therefore have significantly lower risk to humans. Termite baits prepared with mirex were shown to be highly effective in controlling subterranean termites in field and residential sites in the U.S. and Canada (Beard 1974; Esenther and Beal 1974, 1978; Esenther and Gray 1978; Ostaff and Gray 1975). Perhaps mirex baits would have been the second silver bullet of termite control, but because of the cancellation of the registration of mirex we can only speculate.

The Ant Colony as a Model in Bait Control

Most of us have a stereotyped conception of the structure and organization of an ant colony as having a single queen, hundreds or thousands of workers, and residing in a well-defined nest excavated in soil or wood. Many species of ants send out scouts to locate new food sources, and they communicate information about these food sources to nestmates. Recruitment communication by chemical trail pheromones mediates a rapid build-up of ants at the food. Most species of ants are omnivorous, and liquid carbohydrate foods are a substantial dietary element. Foragers feed on such liquid foods to repletion, transport the food back to the nest, and then regurgitate it to nestmates. If a bait contained a pesticide that had a delayed effect on mortality, then there would be ample time for the active agent to be spread through the colony by trophallaxis, or social food flow. A single forager's food load, passed from worker to worker in a colony, could theoretically kill several ants that have not themselves fed at the bait, including the queen. The bait control technique allows the colony to be directly targeted, minimizing the amount of pesticide required for control.

In the late 1950's, radioisotope labelling studies on the dynamics of social food flow in some species of ants supported that model of colony food distribution, thus indirectly

encouraging the development of baits. However, there are many species of ants with diverse feeding habits (referred to for example as sweet-eating, or grease-eating in the ant control literature) and important differences in digestive tract anatomy and rates of food transfer among workers. Some species do not transfer food at all, and can not store food collected at a source. And many species have multiple queens and multiple nests. Based on the stereotyped, simplistic model of colony organization outlined above, baits are theoretically the best way to control ants. But the biology of many species could be very different from what we imagine to be true and may place strong limits on the degree of efficacy.

Termite Biology: The Facts Behind The Bait Concept And Their Relevance To Control By Baits

In the previous section of this paper we described the concept of bait control in reference to the biology of a "generic" species of ant, that is, one having biological characteristics that seemingly make it easy to control with baits. Of course, there is no such thing as a "generic" ant, and there is no bait that is universally effective against the many pest species. Different species of ants have different biological characteristics. Some have more than one nest, and colonies can be spread over large areas. Certain species may have several or even hundreds of queens. And the food sources used by a species will determine its search behavior, foraging pattern, and food preference.

The number of economically important species of subterranean termites is much lower than the number of pest ant species, and they seem to be more similar biologically, as most fall into three genera, *Reticulitermes*, *Heterotermes*, and *Coptotermes*, all members of the family Rhinotermitidae. But the biology of these species has only been inferred from a relatively small number of studies that attempt to probe into wood and monitor

activity beneath the ground to gain insight into colony size, structure, social organization, and foraging behavior (Esenther 1969; Grace et al. 1989; Haverty et al. 1975; Jones 1990; Su et al. 1984, e.g.). In the next section of this paper we discuss some of what is known and unknown about the biology of subterranean termites, as is pertinent to baiting, and how the success of termite control by baits will depend upon the accuracy and depth of our knowledge of termite biology.

Biological Unknown: Colony Structure

What constitutes a colony of subterranean termites like *Reticulitermes flavipes*? All indications are that it is nothing like the colony structure of *Macrotermes* with which we introduced the topic of this paper. In fact some of the basic tests that are used to characterize social insect colonies fail to give us insight into *Reticulitermes*. For example, workers of many species of social insects attack workers from other colonies. This simple test tells you if workers collected at two locales are from the same colony. Esenther (1969) reported that no such aggressive behavior occurs when larvae of *Reticulitermes flavipes* from different sites in Wisconsin were mixed. Our own research generally supports these studies (Traniello and Thorne, in prep.). We have found that it is possible to combine *R. flavipes* larvae collected at sites in Massachusetts separated by miles without any aggression; fighting in these mixed colonies is rarely seen. Moreover, larvae collected from local and remote sites in New York, Pennsylvania, Maryland, and Texas can also be combined without fighting. Detailed ethological studies on these mixed groups show that frequencies of social behaviors such as allogrooming and trophallaxis are not different from those in control groups. We now need to extend these studies and determine the social contexts in which aggression may occur.

These results suggest that *Reticulitermes* "colonies" are decentralized; there may not be one central nest or chamber containing all the reproductives. The number of

replacement reproductives in a "nest" may reach several hundred, and both primary and replacement reproductives may move under field conditions (Howard and Haverty 1980; Snyder 1935, 1954). There may be replacement reproductives in more than one satellite "nest" connected to other similar units by a network of galleries or trails. Over time, these connections between "nests" may be severed and the interactions between the occupants may decrease, slowly fragmenting the original "colony" as it effectively reproduces by budding (Esenther 1969).

The relevance of the structure of a colony and the number of reproductives in a nest to the efficacy of baiting is straightforward. If a colony is centralized (occupies a limited amount of nest space and has a core area of activity) and has a limited number of reproductives, then a relatively small number of baits placed strategically within its foraging range should prove effective in control. But a colony having many reproductives and a strongly decentralized structure, perhaps with reproductives occupying several different sites, will present a challenge for baiting if the goal is eradication.

Biological Unknown: Frequency of Food Exchange And Extent of Social Food Flow

One of the reasons that ants have served as a model of the ideal social insect species to control with baits is that food sharing, or trophallaxis, among colony members is a readily observed and prominent aspect of social life in many common pest species. Bait technology relies on a fraction of a colony feeding directly at a pesticidal bait and then transporting the pesticide (for example, a delayed-action toxicant, growth regulator, or pathogen) in the bait to colony members that have themselves not fed at the bait. Trophallaxis is the mechanism by which toxicant is transmitted throughout a colony. If the frequency of trophallaxis is high, then toxicant will be rapidly distributed through a colony and the titre of pesticide will ultimately rise to a lethal level *before* it produces an

effect in most individuals. Then like a ticking time bomb, it produces high mortality in the colony, perhaps even killing the reproductives.

On the other hand, if trophallaxis is slow and the frequency of food sharing among nestmates is low, then individuals that feed directly at the bait may die before they have distributed sufficient toxicant to produce mortality in other colony members. In this case there will be only the death of the portion of the colony that has actually fed at the bait.

Carpenter ants, *Camponotus pennsylvanicus*, would seem to be an ideal species to control with baits because social food flow is rapid. Using radioactive phosphorus as a label in food, it has been demonstrated that a forager that has fed at a liquid food source transfers as much as 98% of her load of food to nestmates within 10 minutes of her return to the nest (Traniello 1977). This means that toxicant would be quickly distributed throughout a colony. But other ant species are highly variable in their tendency to transfer food to nestmates; some species show no trophallaxis at all (Wilson and Eisner 1957).

Beard (1974), using an isotope of carbon to label a filter paper food source, found that trophallaxis occurs at a relatively low rate in small artificial colonies of *Reticulitermes flavipes*. Traniello (unpublished data) using radioactive phosphorus as a food label, confirmed these results. Our behavioral observations of oral and anal food exchange in *R. flavipes* support the idea that these termites do not share food at high frequencies. In many species of ants food exchange is one of the most common acts seen in a colony; in *R. flavipes*, it seems to be relatively rare.

Again, such a feature of basic biology is important to the design and implementation of termite baiting programs. As we just outlined, a low frequency of trophallaxis will yield a poor distribution of pesticide among colony members that have not fed directly at the bait. Secondary kill may not contribute significantly to mortality if social food flow is too slow, and baits and baiting strategies will have to be designed with this constraint in mind.

Biological Unknown: Search Behavior and Foraging Site Fidelity

The cryptic habits and large colony size of subterranean termites make them difficult subjects for the study of foraging behavior. A great deal is understood about the foraging behavior of ants (reviewed in Traniello 1989) but in contrast to ants, subterranean termites forage below the soil surface, have small body size, and are difficult to mark and identify as *individuals*. The ability to recognize individuals in social insect colonies has produced great advances in understanding their foraging behavior, but we have only begun to apply this method of study to termites. Presently, it is difficult if not impossible to follow termites in the field, and it is only somewhat less difficult to follow individuals in the lab.

The inability to follow individual subterranean termites as they search for food under natural conditions means that a great deal of termite foraging behavior and its ecological correlates remains unknown. The aspects of foraging biology that are most important to the development of bait technology include the search behavior, which may have seasonal components, and the site fidelity of individual termites. The former will affect the rate of discovery of baits, and the latter translates into the residence time of termites at a bait. If individuals make repeated trips to a bait, then they may slowly acquire enough toxicant to produce mortality while distributing toxic food to others in the nest (depending on the rate of food exchange) and recruiting more nestmates to feed. If the strategy of feeding is "hit and run" (that is, very short individual residence time at a bait), then the amount of food and toxicant collected during a single visit may be sublethal, requiring many feeding periods at baits by each forager. The search pattern and rate of movement of individual termites between foraging sites (fallen trees, rotting wood and roots in the field) is a related variable in termite foraging ecology. For bait technology, this translates into bait visitation rates and the number of baits that need to be discovered to deliver sufficient toxicant to a "colony" to suppress its local feeding activity. It would be convenient for baiting if individual termites continuously moved between feeding sites, as some researchers feel is the case (Su et al 1984). But in fact individuals infrequently change

their site of foraging (as is the case for the majority of social insect species studied), expected baiting efficacy will be lower. The pattern may be modified if the properties of the bait itself can change termite feeding behavior to enhance residence time and the rate of delivery of toxicant to the "colony".

Biological Unknown: Selectivity of Food Sources

Foragers of several species of ants and some termites are known to assess the array of resources that are available to the colony and then feed preferentially on one or a few (Prestwich et al 1980; reviewed in Traniello 1989). But there is little information available on food selectivity in *Reticulitermes*. The degree to which subterranean termites are selective in their feeding habits has perhaps the greatest implications for control by baiting, because it affects the ease with which termites will accept a bait. To the extent that subterranean termites are dietary generalists, eating most cellulose sources they encounter, the bait material itself will be less critical to bait efficacy. But if they do show choice in feeding, and in fact are highly selective among available resources, then such behavior will pose a significant problem for baiting.

It will be extraordinarily difficult or impossible to remove competing food sources when implementing termite control by baiting. Residences may be in wooded areas with stumps and fallen limbs on the ground and roots in the soil. Neighbors may have woodpiles and rotting fence posts nearby, and construction debris might be buried near the house. Thus termites are likely provided with abundant and persistent sources of cellulose that can be fed on in addition to or in preference to baits. The volume of such cellulose sources alone will pose a significant problem. It will be critically important that the properties of the bait are able to induce feeding and recruitment, thus minimizing the impact of having termites drawn to competing foods. Successful bait formulations will not

incorporate substances that "attract" termites, but will be composed of materials that are fed on in preference to other available foods.

A PROSPECTUS FOR FUTURE RESEARCH

If the philosophy of "knowledge for its own sake" can not alone support the need to conduct research on the basic biology of pest insects, then the concept of understanding basic biology of insect pests to identify the so-called "weak links" that can be exploited to control them should provide significant rationale. In attempting to control subterranean termites, it seems barely possible to exploit their vulnerability because we have only a minor understanding of their life history, behavior, and social organization. We need more research by more research groups, working cooperatively to transform inquiry in behavioral and ecological processes into tactics for control. The economic importance of termites should make the call for basic work loud and clear.

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Control of Drywood Termites (Isoptera: Kalotermitidae)

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ABSTRACT: Drywood termites are economically important pests of sound, dry structural lumber in the southern U.S. and subtropics and tropics worldwide. A broad variety of detection, prevention, and control methods have been used against drywood termites. Remedial control strategies are classified as either local (direct application to infested wood) or as whole-structure treatments and employ either chemical or non-chemical means. Scientific evaluations are severely limited or lacking for some currently used drywood termite control methods. Future research should also focus on new active ingredients and formulations for local treatments and increased knowledge of drywood termite biology.

KEYWORDS: *Cryptotermes*, *Incisitermes*, detection, fumigation, local treatments, non-chemical treatments.

INTRODUCTION

Drywood termites (Kalotermitidae) constitute a diverse and primitive family of about 400 wood-dwelling and one soil-inhabiting species (Krishna 1961, Scheffrahn unpubl.). Less than one-tenth of these are either primary or occasional pests of sound, dry structural lumber and

wooden furniture and occur in all tropical, subtropical, and some temperate regions. *Cryptotermes*, *Incisitermes*, *Neotermes*, *Glyptotermes*, and *Kaloterme*s contain the bulk of pest species worldwide (Harris 1971). If a kalotermitid species requires wood moisture greater than that provided by ambient humidity, it may commonly be referred to as a dampwood termite (e.g. many *Neotermes* spp.), but the distinction between "drywood" and "dampwood" is often unclear. In the United States, *Incisitermes minor* (Hagen) and the more xeric-adapted *Marginitermes hubbardi* (Banks) are structural pests in the Southwest, while *I. snyderi* (Light) and the introduced *Cryptotermes brevis* (Walker) are the dominant pest species in the southeastern states (Banks and Snyder 1920, Hunt 1949, Snyder 1954, Weesner 1965). Texas has a transitional mixture of structure-infesting drywood termites including *I. minor*, *I. snyderi*, and *C. brevis* (Howell et al. 1987). *Neotermes jouteli* (Banks), *N. castaneus* (Burmeister), and *C. cavifrons* Snyder may also occasionally infest structural wood in peninsular Florida if sufficient wood moisture is available (Scheffrahn et al. 1988). In Hawaii, *C. brevis* was introduced near the turn of this century (Fullaway 1926) and it remains the islands' only pestiferous drywood termite (Bess and Ota 1960). Nearest to the continental U.S., structural infestations of drywood termites are common in the West Indies (Scheffrahn et al. 1990) and Mexico (Nickle and Collins 1988).

Drywood termites account for a considerable portion of the over \$1 billion in damage and control costs attributed to termites in the U.S. (Su and Scheffrahn 1990). Most estimates of losses from termites combine those of drywood and the more widely distributed subterranean species. A 1983 estimate of \$105 million (Hamer 1985) was attributed specifically to drywood termite losses in Florida. In 1987, the cost of fumigations for drywood termite control in southern Florida was conservatively estimated at \$30 million (Scheffrahn et al. 1988). In the city of Corpus Christi, Texas, drywood termites accounted for over \$2 million of the \$3.7 million in total termite losses during 1979 (Granovsky 1983).

Drywood termite colonies nest and forage solely in wood and give only subtle outward signs of their presence except during brief dispersal flights. Therefore, they are easily and unwittingly transported during the movement of infested goods, containers, or ships. At least six species have been introduced across oceans by the human transport (Gay 1967). Once introduced into warmer climates, drywood species often thrive. New arrivals may even flourish in heated structures in cold temperate regions (Grace et al. 1991). In Florida, *C. brevis* was introduced into Key West before 1918, probably from the West Indies (Snyder 1934). More recently, structural infestations of *I. minor* have been regularly encountered in southeastern Florida (Hickin 1971, Scheffrahn et al. 1988) as a result of multiple introductions from the southwestern U.S.

Harvey (1934a,b) provided a detailed description of the behavior, colony development, and native and structural habitats of *I. minor* in southern California. Harvey's work remains the mainstay of our

understanding of drywood termite biology and can be generally applied to describe the life histories of other structure-infesting kalotermitids. Luykx (1986) and Luykx et al. (1986) provide additional detail to caste proportions and spatial distributions of castes, respectively, in *I. schwarzi* (Light) colonies in Florida mangrove wood. Alate dispersal and new colony establishment of *C. havilandi* (Sjöstedt), a drywood pest in tropical Africa and America, was documented by Wilkinson (1962). Minnick (1973) recorded the flight and pairing behavior of *C. brevis* in Key West, Florida.

Probably a greater variety of methods have been developed, marketed, and ultimately sold to the American public to control drywood termites than any other structural or household pest (Table 1). There are several reasons for this plethora of treatments. One of the greatest determinants of treatment choice, and often one of the most uncertain and difficult to ascertain, is the location and extent of a drywood termite infestation. A single colony may reside in a small piece of furniture which can simply be discarded. A constant trickle of fecal pellets from a wooden door signals an infestation and, in this case, access is unhindered and local treatment is a feasible choice. Finally, a structure may contain many infested wooden members, each infested by one or more colonies. Accessibility to each or all colonies may be severely limited. In such a case, fumigation and, possibly heat treatment may be the only viable means of complete control. Other considerations such as treatment cost, aversion to chemicals by the homeowner, convenience, chance of success, and local availability of a given treatment all dictate what method will be chosen.

This paper reviews the methods used, past and present, to detect, prevent, and control drywood termites in structural wood.

DETECTION

Before any treatment for drywood termites can be performed, the existence and extent of the infestation must be confirmed and diagnosed. Better yet, pinpointing the exact location of termites within their gallery system will ensure more effective control if a local treatment is to be applied. The ability to detect termite activity also allows the pest control operator to monitor the success or failure of a given treatment. Drywood termite detection currently relies primarily on wood probing and visual inspection (J. Mangold, Terminix Intl., pers. comm.). Canine olfaction and a variety of sound (electronic stethoscope) and metabolic gas/water vapor detection devices have been used to locate drywood termites, but each of these methods has its respective shortcoming: inherent difficulties in using dogs, interfering audible background sounds (Scheffrahn and Su, pers. obs.), and the lack of methane production (G. Wheeler, unpubl.) or moisture association by drywood termites.

Technological advances in filtration of background acoustics and amplification of termite-generated acoustic emissions, however, have

TABLE 1. SUMMARY OF DRYWOOD TERMITE CONTROL METHODS^a

I. PREVENTATIVE		II. REMEDIAL	
		LOCAL OR "SPOT"	WHOLE-STRUCTURE
A. Chemical	1. Surface Applications	A. Chemical	A. Chemical
	a. Wood preservatives		
	(1) Chromated copper arsenates	1. Surface Applications	1. Fumigation
	(2) Creosote	a. (Pentachlorophenol pas)?	a. Methyl bromide
	(3) (Pentachlorophenol)?	b. (Lindane/oil)?	b. Sulfuryl fluoride
	(4) Borates?	c. Borate solutions?	c. (HCN)
	b. Insecticides	2. "Drill and treat"	d. (Acrylonitrile)?
	(1) Organophosphates?	a. Aerosol	e. CO ₂ synergism
	(2) (Organochlorines)?	(1) Organophosphates?	
	c. Residual alate toxicants	b. Dusts or powders	B. Non-Chemical
	(1) Silica gel	(1) (Arsenicals)	1. Heat?
	(2) Borate dust or liquid	(2) Silica gel	
	2. "Drill and treat"	(3) Carbamates?	
	a. Wood preservative	(4) (Chlordane)?	
	(1) Fused borate rod?	c. Liquids	
		(1) Borates?	
		(2) (DDT)?	
		3. Local liquid fumigant	
		a. (EDB)?	
		b. (Trichlorobenzene)?	
		B. Non-Chemical	
		1. Electrocuting?	
		2. Cold, liquid nitrogen?	
		3. Heat?	
		4. Microwave?	
		5. Nematodes?	
		6. Damaged wood replacement	
B. Non-Chemical			III. DETECTION
1. Alate excluders?			A. Visual damage/probing
a. Caulking?			B. Dispersal flights
b. Paints or coatings?			C. Acoustic emissions
c. Foundation/attic screening			D. Electronic stethoscope?
2. Termite-resistant wood			E. Methane/waste gases?
3. Non-wood construction			F. Canine olfaction?

^a () indicates an outlawed method in the U.S. ? indicates little or no published efficacy data as of March 1994.

tremendously improved the prospect of detecting drywood termites and other wood-feeding insects. A study by Scheffrahn et al. (1993) demonstrated the performance and feasibility of using a hand-held, battery-powered acoustic emissions (AE) detector designed and built by W. Robbins and R. Mueller (University of Minnesota) to locate and monitor termites. It was concluded that this device offers a reliable method for localized, non-destructive detection of termites feeding on wood. An updated model, released in 1993 by DowElanco for field testing, can detect termite feeding from a sensor distance of up to 70 cm (Scheffrahn unpubl.). An inspector would simply place a sensor on the surface of wood which he suspects to harbor drywood termites based upon Packard's (1951) list of existing visual evidence such as pellets, kick-out or emergence holes, or characteristic surface damage. The AE detector would confirm or refute the presence of live termites and be useful in verifying the success of a control treatment.

PREVENTION

Prevention of drywood termite infestations follows two approaches: making wood unpalatable to termites or preventing establishment of founding colonies by controlling or excluding winged and dealated reproductives during their short dispersal forays and nuptial chamber construction. Unpalatability includes using termite-resistant lumbers (Scheffrahn 1991) or susceptible lumber treated with wood preservatives (Hunt 1959, Randall and Doody 1934a). Because dispersing reproductives (alates) seek dark habitation after flight, attics, voids in walls and furniture, and crawl spaces are often foci for colony establishment. Silica aerogel dust was recommended as the choice desiccating toxicant for attic and wall void treatments to kill alates (Ebeling and Wagner 1959) and was shown to be toxic in the laboratory against *C. brevis* (Minnick et al. 1972). Borate dusts may also be suitable residual alate toxicants. No data are available to show if this method actually decreases the incidence of infestation but a thorough application of such surface dusts would likely have some desired effects. No work has been done on the effect of structure or wood exclusion devices against alate entry such as attic vent, foundation, and window screening, roofing material, caulking, or wood coatings.

WHOLE-STRUCTURE REMEDIAL TREATMENTS

Structural fumigation with methyl bromide (BROM-O-GAS) or sulfuryl fluoride (VIKANE), administered per label directions, will completely eradicate drywood termites from a structure (Stewart 1957, Bess and Ota 1960, Osbrink et. al. 1987, Scheffrahn and Su. 1992). Therefore, this has been the treatment of choice when drywood infestations are

extensive or difficult to access or delineate. Early fumigants included, most notably, hydrocyanic acid (Hunt 1949) and acrylonitrile. The inherent disadvantage of fumigation is the lack of residual protection. In California, where fumigation is often required prior to closing the escrow of infested structures, about 150,000 dwellings are fumigated annually. However, concerns about human exposure to fumigants has spawned new stringent laws governing structural fumigation practices in California (Anonymous 1992), and new restrictions will likely be adopted by other states. Methyl bromide has been recently implicated as a significant depleter of atmospheric ozone and is scheduled to be phased out by the year 2001 under USEPA guidelines (Kramer 1992, Anonymous 1993a) leaving only one viable fumigant, sulfuryl fluoride, in the marketplace. The quantity of fumigant used to treat an average size home, approximately 5-10 kg, also puts structural fumigation at risk as this amount greatly exceeds the active ingredient requirements for most other standard pest control practices.

Carbon dioxide (CO₂) has long been known to enhance the toxicity of fumigants to control insects infesting raw food commodities (Cotton 1932); however its use was not developed for structural fumigation until recently. In 1993, California and Florida approved a structural fumigant label under the MAKR brand for the application of methyl bromide at 8 mg/l in admixture with CO₂ at 176 mg/l (10% v/v) for a 16-24 hour exposure (Anonymous 1993b). Laboratory studies by Scheffrahn et al. (1994) revealed that 5-10% CO₂ combined with methyl bromide or sulfuryl fluoride appreciably synergised the toxicities of both fumigants against *I. snyderi* psuedergates ("nymphs") by up to about 1.8-fold, equal to a reduction in required fumigant concentration of about 45%.

The outlawing of some effective localized chemicals (e.g. arsenic dusts, ethylene dibromide, pentachlorophenol, etc., see below) in developed nations has intensified the reliance on structural fumigation for drywood termite control, especially in the United States where the cost is tolerated by necessity. Because fumigation is technically complicated and expensive, and regulatory concern about the practice is mounting (Calif. Struct. Pest Control Board, Pers. Comm., R. Sbragia 1992), there is a need to develop effective alternative treatments.

In recent years, treatment of structures by heat has been promoted as a non-chemical means of whole-structure eradication of drywood termites (Forbes and Ebeling 1987). Although investigations have been conducted on the temperature and humidity preferences (Steward 1981, 1982) and desiccation tolerance (Pence 1956, Minnick et al. 1973) of drywood termites, little research has been done on the use of heat as a control measure. The thermal limit for *I. minor* has been estimated at 49°C for 33 minutes (Forbes and Ebeling 1987) to 52°C (time not specified, Randall and Doody. 1934a). Although drywood termites can be killed by elevating ambient temperatures above the termites' lethal thermal limits, the temperatures and exposure times for each target species must be determined experimentally. In addition, the effects of relative humidity

and gradual seasonal temperature acclimatization on heat tolerance of drywood termites must be investigated. Finally, temperatures must be monitored inside wood members at distant locations throughout a structure during field trials to insure that maximum lethal temperature/time exposures are attained without causing adverse effects on the structure or its contents. At present, fumigation, and possibly heat treatment, although expensive, are the only viable means of whole-structure, single treatment eradication of drywood termites.

LOCAL REMEDIAL TREATMENTS

Local or "spot" treatment for drywood termites is recommended when the extent of an infestation can be delineated and is at least partially accessible. The lower cost and greater convenience of most local treatments also makes them more attractive than whole-structure treatments. However, Ebeling and Wagner (1964) observed a higher frequency of "reinfestations" in attics treated with local remedies than those which were fumigated. Local treatments fall under two categories, non-chemical and chemical. Chemicals registered for spot application can be further classified as to mode of application: onto wood surface (liquid applied by spray or brush); and intragallery injection termed "drill and treat" by Packard (1951). Disodium octaborate tetrahydrate formulations are currently being used in aqueous or dust (TIM-BOR), aqueous glycol (BORA-CARE), or foam formulations as unpainted wood-surface treatments for both control and prevention of drywood termites. Although testimonial reports by pest control operators using borates have been positive, scientific data to support these claims are minimal. Until its outlaw, pentachlorophenol, applied in a petroleum-based paste (Woodtreat-TC), was the treatment of choice on bare infested wood surfaces (Ebeling 1978).

Although published efficacy data are lacking, the practice of injecting a mixture of ethylene dibromide (EDB) by itself or with a residual chemical such as chlordane, DDT, or other organochlorine, was successfully used as a drill-and-treat formulation (Ebeling 1978). The EDB volatilized throughout the gallery network as a local fumigant. The organochlorine additive was intended to give long-term residual protection. Trichlorobenzene was suggested for use in the same manner as EDB (Snyder 1950). All these materials are no longer registered for use in the U.S. The concept of a local fumigant for drywood termite control warrants reinvestigation as it has been shown that insects are susceptible to the gaseous phase of a number of non-halogenated volatile organic compounds based on natural products (Dettner et al. 1992). Currently, aerosolized organophosphates such as chlorpyrifos (PT-270 Dursban) and safrotin are the most popular and easy-to-use drill-and-treat formulations.

Many chemicals currently used in drill-and-treat applications in the U.S. rely on acute contact toxicity. Such insecticides may be repellent or

deterrent to drywood termites. Drywood termites in untreated wood galleries might avoid foraging in treated portions of their gallery system, and thus survivors might reinstitute colony development and redirect damage elsewhere in the wood members. Control success with these compounds is also related to treatment coverage which, in turn, depends on the accessibility of infested wood. Therefore, control rendered by current drill-and-treat applications may be limited to small areas because only termites in chemically-treated galleries are certain to be contacted by the toxicant.

The effectiveness of most spot treatments for drywood termite control has not been adequately evaluated. There is one notable exception. Randall and Doody (1934b) showed that Paris green or copper aceto arsenite dust, when injected into galleries at 1-meter intervals, could successfully control extensive infestations of drywood termites in utility poles. Only 1 gram of arsenic dust was sufficient to treat a large infestation. The efficacy of Paris green was attributed to its slow activity and non-repellent quality against termite workers which, when contaminated, would actively spread the toxicant among uncontaminated nestmates. Any nestmates foraging in treated galleries would, likewise, be contaminated. Smith (1930) also noted the success of field tests with Paris green dust against *I. minor*. A formulation of 35% calcium arsenate (KALI-DUST) was a mainstay product in drill-and-treat applications for many years. Working with and injecting this dust was messy and exposed the pest control operator to the toxicant. Arsenic dusts, because of their acute mammalian toxicity and carcinogenicity, are no longer registered for pest control in the U.S.

Local non-chemical treatments, including thermal and electrical current applications, are presently the most controversial treatments. Both heat and cold have long been considered for drywood termite control (Snyder 1950). Low temperature spot treatments are being conducted with the application of liquid nitrogen in the proximity of infested wood members in wall voids or areas where infestations can be enclosed by insulation blankets (Emshwiller 1989, Forbes and Ebeling 1986). Cold treatment using liquid nitrogen should not be considered a whole structure treatment as claimed by some providers. Local heat treatments, termed "isolation treatments" are applied to portions of a structure to which the drywood termite infestations are limited (Ebeling 1994). In Florida, heat treatment is currently being used to treat only infested portions of structures such as single units of large condominium buildings (J.A. Chase, Terminix Intl. pers. comm.) Microwave (high frequency electromagnetic energy) spot treatments are currently being sold in California to control drywood termites by microwave heating (V. Lewis, pers. comm.). A device called the "electrogun" which produces a high-voltage, high frequency electric current (Ebeling 1983) has been used for over a decade. As with most chemical treatments, scientific evaluations of the efficacy of non-chemical control methods are lacking.

At present, no biological control agents have been marketed for

drywood termites. A field trial with *Heterorhabditis* sp. nematodes on the Sri Lankan drywood termite, *Glyptotermes dilatatus* (Bugnion and Popoff), suggests that control is possible by intragallery injection of nematodes in woody stems of infested tea plants (Danthanarayana and Vitarana 1987). However, the extremely dry conditions of typical structural infestations would present a much greater challenge to nematode survival and movement (R. GIBLIN-DAVIS, pers. comm.).

RESEARCH OUTLOOK

The growth and movement of human populations in the United States, and worldwide, have spawned increases in the use and transport of structural lumber and wood products to meet construction demands (Edwards and Mill 1986). Therefore, future long-term increases in the prevalence, damage from, and need to prevent or control drywood termite infestations, is assured. How, then, can research meet the demand for safe, effective, and low-cost controls? First, scientifically unsubstantiated methods must be thoroughly evaluated. Further data on these methods need to be generated to optimize their performance for a given drywood termite species and geographic region.

Currently, a group of California researchers are investigating the various "alternative" treatments. Vernard Lewis (U.C. Berkeley) and Mike Haverty (USDA For. Serv.) are comparing full-scale thermal (including microwave) and electrocution treatments with structural fumigations. Michael Rust and Thomas Atkinson (U.C. Riverside) are studying the efficacy of liquid nitrogen applications and reviewing the current drywood treatment trends in southern California.

In Florida, our work is focusing on the development of improved local chemical treatments. Our most promising research aims to identify spatially non-repellent, non-deterrent (feeding), and slow-acting termiticides for use in drill-and-treat applications against *I. snyderi* and *C. brevis*. Candidate compounds will be screened and formulated for minimum termite avoidance and maximum coverage. It is hoped that a chemical treatment will be identified that will maximize drywood termite mortality with a minimum number of application sites. In essence, we are seeking a replacement for arsenic dust.

Finally, attention must return to the basic understanding of drywood termite biology and behavior as was the focus of Harvey's (1934a,b) pioneering work. Research into the foraging dynamics of drywood termites may yield the greatest applied gains. Likewise, knowledge of foraging dynamics has been critical in the development of subterranean termite control bait (Su 1994). If we can learn how far and to what extent drywood termites forage within their gallery system and the level of interaction with their nestmates, we can devise an optimum local treatment protocol.

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VERTEBRATE AND ARTHROPOD PARALLELS IN URBAN PEST MANAGEMENT

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ABSTRACT: This paper discusses parallels in the behavior, biology and pest management technology between two of the most significant urban pests, the German cockroach, *Blattella germanica*, and the house mouse, *Mus musculus*. These pests are cryptobiotic animals exhibiting parallels in movement, feeding, and habitat selection behaviors within the artificial environments of human structures. These parallels in turn, influence the similarities that exist within the pest management approaches for these pests, especially relative to baits and baiting technology. The characteristics important for effective baits and bait formulations are similar for rodenticides and blattellicide baits as are the abiotic and biotic factors affecting the success of baits for both pest groups. Consequently, the principles of effective baiting strategies in the broad context is applicable to both pest groups. These principles have practical value for pest management professionals in designing and implementing baiting programs for cockroaches, rodents, and perhaps ants, termites and other pests.

KEYWORDS: German cockroach, house mouse, pest management, baits.

INTRODUCTION

Technically, the science of Urban Entomology concerns the study of arthropods relative to the urban environment. From an applied aspect however,

the field of Urban Entomology usually also includes vertebrate pests (Ebeling 1975). Moreover, the terms *urban entomology* and *urban pest management* are often used in conferences and publications interchangeably. Certain vertebrates, specifically the commensal rodents, are an integral component of urban pest management and rank in similar importance bionomically and aesthetically to the major arthropod pests. This is pointed out because cockroaches, ants, termites (and likely other insects) share with the commensal rodents and other vertebrate pests several biological, behavioral and pest management parallels. The illustration of these parallels between the two phyla may provide additional insight for various scientific purposes such as the designing and development of baits. Or, from an applied perspective, the designing of various inspection, monitoring and pest management programs.

The purpose of this paper is to present an overview of the parallels that exist between the insect and vertebrate phyla in the urban pest management arena. To illustrate these parallels, this presentation focuses on two of the most important urban pests: the house mouse, *Mus musculus*, and the German cockroach, *Blattella germanica*, although similar and additional parallels also exist between the vertebrates and other arthropods (e.g., ants, termites).

A. BIOLOGICAL AND BEHAVIORAL PARALLELS

Several different biological and behavioral parallels can be drawn between the German cockroach and the commensal rodents. The more significant parallels are listed in Table 1 and discussed below. Other parallels (e.g., exploratory activity, competition behaviors, grooming behaviors, etc.) exist, but these will not be discussed here.

Cryptobiotic Pests

The synanthropic species of cockroaches and rodents are cryptobiotic animals possessing biology and behaviors that are "secretive" relative to human activity (Ebeling 1975). These animals are active at night, utilize secluded, hidden, or inaccessible areas harborages, and are attracted towards darkened or shadowy areas during activity periods. Additionally, the cryptobiotic nature of these pests is accentuated due to their quick movements in response to possible adversity and their habit of generally remaining close to their harborage. For example, roaches and rodents scurry for nearby cover when they detect vibrations and/or movements enabling them to often escape capture or detection. As a result, these pests often remain undiscovered by people until their numbers increase. It is this cryptobiotic behavior, which in part, is responsible for the public to often perceive that these pests seemingly appear "from nowhere".

Movement, Orientation, and Harborage Selection

Cockroaches and rodents utilize sensory feedback for orientation, movement and harborage selection. Cockroaches employ their antennae, mouth parts, and various setae on the body to receive thigmotactile feedback to surfaces (Cornwell 1968). In addition to seeking necessary micro-climates,

TABLE 1-- Some biological and behavioral parallels of G. cockroaches and commensal rodents.

	German cockroaches	Commensal Rodents
Orientation and Movement		
a. Sensory	Tactile:Thigmophilic Antennae, body setae	Tactile:Thigmophilic: Vibrissae, guard hairs
b. Pheromonal cues	Aggregation and other pheromones	Pheromonal marking of runways; feeding, mating, and nesting areas.
c. Structural guidelines	Utilize various ledges and structural lines during foraging and movement	Utilize various ledges and structural lines during foraging and movement
d. Learning and retention of movements	Learned behaviors	Learned behaviors; kinesthetics
e. Phototropism	Negative	Negative
Activity Periods	Nocturnal	Nocturnal
Feeding Behavior	Omnivorous, random and opportunistic foraging; pheromonal cues	Omnivorous, random and opportunistic foraging; pheromonal cues
Harborage Selection	Thigmotropic micro- habitats; micro-climatic; Established in protected locations near resources.	Thigmotropic habitats. Established in protected locations near resources.

cockroaches tend to "select" environments which provide thigmotactile feedback by utilizing various cracks, crevices, and corners, and by traveling along joints common to two walls or surfaces. This behavior has been reported in some of the earliest publications on domestic cockroaches (e.g., Haber 1919), and restated many times in subsequent publications discussing cockroach behavior.

Rodents rely on innervated hairs called vibrissae located on the face, head, and other areas all over the body for thigmotactile feedback. Like cockroaches, rodents travel along walls and between objects. They also gravitate towards corners and other protected areas for feeding, grooming and harborage (Crowcroft 1959; Barnett 1988). Such locations facilitate the vibrissae from their backs and sides touching surfaces and providing sensory contact.

Once travel paths and harborages are established, *pheromonal cues* play important roles for both pest groups in the recurring use of such areas as well as assisting conspecifics and immigrants in locating these areas. The literature addressing pheromonal communications among both pest groups is extensive (e.g., Roth and Willis 1952; Bell et al. 1972; Hurst 1987; Ebeling 1991; Frantz and Davis 1991).

With cockroaches (and other urban pests such as ants and termites), the literature discusses the importance of pheromones and pheromone residues being used by insects to lay down foraging paths, aggregate, or arrest near harborage or food sources. With rodents, pheromones are used for similar purposes as those used by insects. Research on the house mouse has demonstrated the use of pheromones for marking new objects, mating and feeding areas, and paths leading to these areas. Laland and Plotkin (1991), demonstrated that food items and areas "marked" with rat feces containing pheromones resulted in increased feeding activity from that food source as compared to unmarked areas. Pheromones also play a critical role in communication among mice in conspecific recognition, colony status, reproductive behavior, aggression, and other factors.

In addition to sensory assistance, cockroaches, ants and rodents also utilize similar methods for general navigation and travels. Rodents for example utilize a kinesthetic sense--a memory of the number of muscular movements--to assist in their daily travels from harborage to resource sites (Southern 1954). The use of kinesthetics has also been reported for insects. Rabaud (1928) in his book, discusses kinesthetics and various other means by which insects and other animals find their way about. Kinesthetics may be utilized by cockroaches as well. Cockroaches are excellent learners, and are capable of retaining information for days (Alloway 1972; Ebeling et al. 1966).

Harborage selection for both cockroaches and rodents are paralleled in that micro-climates, proximity to food, and protection from predators are paramount. Cockroaches, in order to avoid desiccation, require sheltered and restricted habitats. Thus, they select negative-phototropic habitats which offer suitable microclimates (warmth and moisture) and protection from desiccating air

currents amid the protection of crevices, voids, nooks and corners. Berthold and Wilson (1967) showed that the adults and nymphs of German cockroaches "select" specific sizes of cracks and crevices.

Rats and mice are not as vulnerable to desiccation as are insects, but small mammals are at a disadvantage relative to heat conservation due to their high surface area to volume ratio which favors rapid heat exchange with the environment (Jakobson 1981). Rodents, like roaches, seek out various cracks, crevices and corners for physiological maintenance and protective purposes as well--only the sizes of such areas must obviously be larger.

In addition to utilizing harborages which provide the necessary environmental conditions, cockroaches and rodents exploit harborages within structures that simulate their natural protection from their respective mammal and bird predators as both animals share the same predatory defenses: agility and concealment (Cornwell 1968; Barnett 1975). Harborage then, must be more to both pests than just suitable microclimates and protection from the elements. The concealment for cockroaches must exclude the beaks of birds and the reaching limbs of mammals; for rodents the harborage must exclude most larger mammals, and predaceous birds. When rodents construct ground burrows, the circumference of the burrow usually accommodates the size of the rodent and not much else. Like cockroaches, rodents also exhibit negative photo tropic behavior, gravitating towards shadowed areas to utilize the protection offered by such areas.

For both cockroaches and rodents then, structural harborages provide thigmotactile feedback, protection from desiccation, and/or exposure, the elements and predators. These include structural voids, corners, and other types of concealed areas where the myriad of surfaces within buildings and equipment intersect, as well the intersections of shelves, cabinets and many other components of human furniture.

Feeding Behavior

The parallels in feeding behavior between cockroaches and rodents are especially interesting as they can serve to provide insight relative to baiting applications for both pest groups.

Cockroaches are opportunistic, omnivorous feeders that locate food by chance encounter, usually consuming those foods in close proximity to the harborage (Reirerson and Rust 1992). Although hunger is one of the factors influencing the exploratory activity of cockroaches, the physical features of the habitat (e.g., structural features, temperature, humidity, light) are the principal factors influencing the areas cockroaches travel. Food odors are only feebly attractive to cockroaches, and only if they occur in areas normally frequented by the insects or in the routes in which they would normally travel as driven by the structural features (Ebeling 1975).

In general, the commensal rodents are also omnivorous and opportunistic in their feeding habits. They feed on most foods that people consume as encountered during foraging excursions. As might be expected (and as is often the case with many urban pests), the heaviest infestations of rodents and the highest feeding activity occur in areas where cover and food coincide.

Thigmotactile feedback also plays a role in the feeding behavior of rodents. In general, rodents feed in locations where they sense security from predators and/or aggressive colony members. (e.g., Southern 1954; Barnett 1975; Timm and Salmon 1988). Often, such locations are in corners, tight spaces, beneath or behind objects that provide tactile feedback. In competitive environments, food located in open areas is translocated back to the protection of the burrows, or other environs providing tactile feedback (Barnett 1988). This behavior has important implications relative to the use of bait stations in rodent baiting programs. Bohills et al. (1982) found that house mice were more likely to consume food inside small bait boxes that provided tactile feedback as compared to bait in open trays. Thus, in addition to protecting baits from the elements and non target disturbance, enclosed bait containers also provide the rodent with a thigmotactic shelter which encourages feeding activity at the bait site, thereby contributing to better levels of control.

In situations where food is abundant, mice and rats may exploit certain foods and feeding areas more heavily than other areas depending on intrinsic behaviors, the specific food, tactile sensory feedback, pheromonal marking, intra-specific competition and other factors, all of which may reinforce or diminish the continuation of visits (Timm and Salmon 1988; Frantz and Davis 1991).

The parallels of feeding activity between cockroaches and rodents then, is characterized by both pests being opportunistic, omnivorous, thigmotactile, and reinforcing their visits to food and other areas via pheromonal cues. As discussed below, these parallels have relevance to the biotic and abiotic factors affecting baits in urban pest management.

B. PEST MANAGEMENT PARALLELS : BAITING TECHNOLOGY

In a broad context, several parallels exist between cockroaches and rodents in various aspects of pest management. Some examples include the influence of sanitation, baiting programs, trapping programs, and pesticide resistance. Each of these topics presented as parallels are subjects unto themselves. This presentation will focus only on baiting technology. Here, as with the discussion on biology and behavior, the discussion is directed towards the German cockroach and the commensal rodents. Other pests to which baiting technology is established however, (e.g., ants) or being developed (e.g., termites), may also fit well into these models.

Baits and Bait Technology

Although baits are among the oldest of formulations for both insects and rodents, they have been in place and used most consistently as the *primary control approach* for rodents. But insecticidal baiting programs during the past decade have enjoyed a revitalization, and now play a very significant role in urban insect pest management.

Three broad areas illustrate that the models established for rodent baits and baiting technology fit closely to those which are, or can be, considered for insect pests. They are: (1) bait selection and formulation factors; 2) the abiotic and biotic factors affecting bait success, and, (3) strategies in the applied use of baits. These factors, together with the biological and behavioral parallels illustrate how the principles of effective baiting for these major urban pests are similar despite the taxonomic distance between the phyla.

Pesticidal baits - - Regardless of the phyla of the pest, pesticidal bait efficacy depends entirely on the premise that pests must easily encounter the bait, and then show no hesitancy in consuming the bait. Accordingly, bait characteristics must be tailored for the specific pest. Table 2 lists only some of the common characteristics between rodenticide and insecticide baits.

TABLE 2-- A selection of some important bait characteristics for rodenticide and insecticide baits.

Bait Characteristics	Rodents	Insects
A. Selection, quality and composition of food ingredient	+	+
1. Consumption enhancers	+	+
2. Flavors and aroma	+	+
B. Freshness	+	+
C. Formulation Factors		
1. Moisture content	+	+
2. Shape and size of bait	+	+
3. Bait texture	+	+
4. Concentration of ai	+	+
5. Dyes and pigments	+	
6. Additives (pest specific)	+	+
7. Emetics / repellents	+	+

From a broad perspective, the bait characteristics between insecticides and rodenticides, are closely matched for both pest groups, although other bait characteristics may be important depending on the specific pest. With rodenticides for example, certain formulation characteristics such as dyes and the use of emetics and repellents are important relative to baiting hazards to non-targets such as companion animals and people. But with cockroach and ant baits, these particular characteristics are not especially important due to the obvious differences in the quantity, formulation, and location of insecticide bait applications.

Abiotic and biotic factors affecting bait success - - A review of Table 3 illustrates the similarities between the abiotic and biotic factors that improve and decrease bait success for both cockroaches and rodents. This table is adapted from Reiersen and Rust (1992) for comparative purposes to illustrate the parallels. Each of the factors in the table are discussed in detail for cockroaches by Reiersen and Rust and others as cited. But for the purposes of this presentation, only several of the more salient factors are covered.

Table 3 -- Factors that improve and reduce bait success of cockroach and rodent baits.

Abiotic factors: improve success.	Cockroaches	Rodents
1. Sanitation		
a. Reduction in harborage and clutter	++	+
b. Reduction in competitive food	++	++
2. Proper bait placement	++	++
3. Moisture	++	++
Biotic Factors: Improve Success		
1. Bait acceptance	++	++
2. Foraging patterns	++	++
3. No significant pesticide resistance	++	++
4. Limited immigration	++	++
Biotic Factors : Decrease Success		
Learning and repellency	++	++

a. Sanitation - - The impact of sanitation on pest populations and control efforts is widely discussed in the literature. Marsh and Bertholf (1986) provide an excellent discussion and review of this topic. Sanitation is important to both cockroach and rodent control. However, sanitation conditions (as used in this context --the availability of food, water and harborage) conducive to severe infestations of mice and rats will necessarily have to be much more severe than those for cockroaches due to the obvious increased size and resource needs of the larger animals.

From a practical aspect, it is difficult to restrict the food, water or harborage to levels which would crash cockroach and mouse populations entirely. But poor sanitation does contribute towards increases in populations and the dispersal of new infestations to surrounding areas. Although clutter such as papers, boxes, and junk provide harborage for a wide range of pests, and reduce the effectiveness of baits for cockroaches, much more clutter would be needed to reduce the effectiveness of baits on rodents.

Relative reductions in the amount of food affects both pest groups about equally. In the absence or reduction of food, cockroaches and rodents will increase their foraging activities, or disperse to areas providing the suitable food-harborage combination.

b. Bait Placement - - Proper bait placement is crucial for successful baiting programs in both cockroach and rodent control programs. Reiersen and Rust (1992) state that bait efficacy increases as the number of placement increase. They report the excellent results achieved with avermectin baits are likely to be related to the greater number of placements. In this case, the formulation of a powder or gel style bait somewhat *dictates* that the bait be brought to harborage areas (i.e., direct harborage treatment), and thus, the placement of the bait--perhaps more so than the bait itself-- may be largely responsible for the success. Presumably, this would also be the case with other similar formulations requiring direct harborage applications.

This principle holds true for the rodents as well---especially the sporadic feeding of mice (Crowcroft 1959). Therefore assuming several different brands of baits all utilize a good food base and effective active ingredient, proper bait placement might be the "equalizer" among the different brands. In other words, an excellent bait with a superb active ingredient is not likely to compensate for poor bait placement or application.

c. Moisture - - Of course moisture is an important resource to all animals. Cockroaches, like most insects, must have water nearby as they are vulnerable to desiccation. Thus, they often establish themselves close to water sources that also provide warmth and suitable harborage. Reiersen and Rust (1992) mention that the effectiveness of the newer gel baits and some paste baits may be due, in part, to the moisture content of these baits.

Rodents either travel to their water sources or obtain and supplement their needs from foods with high moisture content, especially in areas where water is difficult or costly to obtain. In fact, water rodenticide bait formulations are specifically available for such situations. Recently, a new "gel-style" rodenticide bait block called Aqua Blok™ was developed with the concept of offering moisture and food to the rodent at the same time. However, research addressing whether the moisture characteristic alone increases the general attractiveness of a specific formulation, or if such a formulation is environmentally dependent (i.e., significantly better only in dry environments) would be valuable. An additional question--and perhaps even more interesting--is whether opportunistic feeders have a tendency towards seeking efficient feeding strategies, i.e., satisfying both food and water requirements at the same feeding site?

Foraging patterns - - As previously discussed, German cockroaches rarely travel extensive distances to food and water if these resources are close by. Thus, baits must be brought to the areas where cockroaches will easily find the bait during their daily exploratory excursions. Those factors which increase foraging activity (i.e., decrease available food) tend to favor bait success. In principle, this is true with rodents as well, although rodents obviously have much larger foraging ranges. If abundant food is located close to the rodents' harborage, foraging, in general, decreases (Young et al. 1950). There are many cases, for example of mice remaining within their harborage, if the site provides both food and harborage. Such is the case in food and seed warehouses when mice become established within the pallets of stored commodities such as dog food, grass seed, etc.

Baiting Strategies - - Table 4 lists those factors which illustrate the parallelism between rodents and cockroaches relative to baiting strategies. These similarities would be expected when considering the parallels established in the behavior section for both pest groups.

Although the same factors are present for both groups, the factors are weighted as the impact varies according to the specific pest.

Bait Delivery - - The delivery of bait for cockroaches may be via bait stations placed in areas close to the harborage or administered directly into the harborage (direct harborage treatment) of the cockroaches via gels, pastes, powders or aerosol-style "foam". With rodents, direct harborage treatment with baits is either difficult due to the inaccessibility of the nest, or restricted legally. Thus containerized baiting and the design of rodent bait containers is of paramount importance in rodent control.

Selection of Bait Placement Location - - The selection of locations to apply a particular bait is crucial to both pest groups. In general, pesticidal baits are most effective if administered as close to the pests harborage or travel paths as possible. This is particularly so for the German cockroach. Rodents in most urban situations will forage for distances ranging from 1- 30 m. away from their nests depending on the species, the specific resource availability and environmental conditions. Thus in most cases, effective baiting can be achieved

away from the burrows, as long as it is within the normal foraging range of the rodents, and the high activity areas are properly identified during the inspection. With cockroach bait applications however, placement differences of inches may impact the success of a baiting program (Reierson and Rust 1992).

TABLE 4 - - Common Factors in Baiting Strategies for Commensal rodents and Cockroaches

Factor	Commensal Rodents	German Cockroach
A. Bait Delivery		
1. Container baits / container design	+++	+
B. Selection of bait placement locations	+++	+++
1. Proximity to harborage		
a. Direct treatment to harborage	+ (burrow baiting; rodents)	+++ Cracks and crevices, corners, and voids
b. Foraging trails	+++	++
c. Broadcast baiting		
C. Determination of bait density per activity patterns and home ranges	+++	+
D. Determination of placement dosage	+++	+++

Baiting Density- - Determining bait density per activity pattern and home ranges is more of a concern with rodents than cockroaches as portions of rodent populations may exhibit marked food preferences at specific locations, and may travel specific distances to feed (Timm and Salmon 1988). As a result, careful determination of baiting density is required in rodent control. For example, when baiting for mice in areas of abundant food and shelter, baiting density must be much higher within the home range of the mice to intercept the random and erratic feeding behavior of mice. In such situations, bait placements of only 2-3 meters may be required (Marsh and Howard 1977; Meehan 1984). In situations

of less food and harborage, rodents will extend their daily travels, in which less baiting density would be effective.

With the German cockroaches, dramatic shifts in the foraging range are not likely unless some abiotic factors interact. Therefore baiting thoroughly within the relatively limited areas that provide the cockroaches with harborage food and water is likely to prove successful.

Bait Dosage - - The determination of placement "dosage" is important for both pest groups. In heavy pest infestations, success depends on sufficient amounts of bait being available for all animals over a period of time until control is achieved or re-treatment. In light infestations, and maintenance baiting, small amounts of bait placed in high activity areas or those areas having the highest potential for re-invasion by new animals (i.e., crevices, corners, previously infested areas, etc.) is important for both pests.

SUMMARY AND CONCLUSIONS

Illustrating the parallels that exist between these invertebrates and vertebrates has several useful functions. First, it serves to provide pest management professionals a broad perspective of important similarities of invertebrates and vertebrates in the urban environment. Second, such parallels can assist in the effective implementation of various pest management practices. And third, via the use of previously established bait models for one pest group, such models may prove useful for bait development and baiting technology models for another pest group. In this discussion, for example, perhaps the models long established for rodenticide baits can assist in developing models for various insecticidal baits.

Relative to baits and baiting technology, this paper presents several basic principles of baiting that apply to both insect and vertebrate pests in the urban environment based on the above parallels. Moreover, some of the parallels illustrated for the German cockroach and commensal rodents may also be applicable to other urban pests which are fitted for baiting programs, such as fire ants, carpenter ants, and termites. Obviously, these species would also have additional specific abiotic and biotic baiting program factors.

Based on the above parallels and discussion, several principles of effective baiting for both cockroaches and rodents are summarized below, although other principles could be added to those provided here.

1. Correct bait placement is paramount.

Baits must be brought to the pest. Baiting for pests is much like the three rules of real estate: location, location, location. Many urban pest species display opportunistic responses to most food items providing the bait is acceptable and competes with other available food. Pests are not likely to travel "searching" for a bait which is superior to nearby acceptable food

items. For cockroaches, direct harborage baiting is indicated to be most efficacious.

2. Baits do not attract pests from distances due to bait odor.
Previous research for both cockroaches and rodents indicate that these animals rely on their sense of smell to locate food only at close distances. For example in the food industry, some quality assurance managers and plant inspectors oppose the use of exterior baits for rodents fearing unnecessarily, that baits will attract rodents to the building perimeter.
3. Once encountered, baits must compete with other available food sources.
Baits must not be degraded or rancid (molds, fungi, dirt, slime, etc.), or be contaminated by insecticidal sprays or other chemicals as they are likely to be rejected in favor of nearby acceptable foods.
4. The selection of a particular bait formulation and bait delivery method (i.e., bait containers or direct harborage baiting) should be evaluated according to pest-specific, site-specific and environmental-specific conditions for each pest situation.
One type of bait formulation may be appropriate for a specific situation and less effective against the same pest in a different situation. With cockroaches for example, a containerized bait formulation may be the obvious choice if there are not easily accessible cracks and crevices to administer gels, powder, or aerosol-style baits directly to the harborage. Container baits are also the obvious choice when baits need to be placed in open or semi-open areas requiring protection from human and other non-target interaction. With rodenticides, the use of a meal bait formulation or a secured block formulation has utility in areas where bait translocation may be a threat preventing the use of a pellet formulation of the same active ingredient.

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PHARAOH ANT BIOLOGY AND CONTROL

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ABSTRACT:

The Pharaoh ant, Monomorium pharaonis (L.), is a pest ant that occurs throughout much of the world. It is considered an urban pest because it invades dwellings such as houses, apartments, bakeries, hospitals, etc. Pharaoh ants are difficult to control because of their ability to reproduce by budding, initiation of new colonies without the presence of a queen, and inaccessible nests. Current control techniques use toxic baits, dusts or sprays. Baits are usually the most effective and contain stomach poisons or insect growth regulators (IGRs) as the active ingredients.

KEYWORDS: Baits, Biology, Control, Monomorium pharaonis (L.)

INTRODUCTION

The Pharaoh ant, Monomorium pharaonis (L.), is a small ant ca. 2 mm long ranging in color from yellow to light red. It is cosmopolitan in its distribution (Wheeler 1910). The Pharaoh ant is thought to have originated in South America (Arnold 1916), or the Afrotropical region (Bernard 1952); however, Bolton (1987) submits that it originated in India, which is in agreement with Emery (1922) and Wilson & Taylor (1967). Because of the pest's widespread distribution, its place of origin will probably never be determined.

Infestations can occur in many areas but are especially troublesome in large office buildings and apartment complexes, factories, food establishments, and hospitals (Edwards 1985). In addition to being a nuisance, in hospitals it causes problems by contaminating equipment and sterile packaging, penetrating intravenous solutions and tubing, and feeding on dressed wounds. Worker ants can carry several pathogens such as Pseudomonas, Staphylococcus, Streptococcus, Clostridium, Salmonella, and Serratia spp. (Beatson 1972).

BIOLOGY

Pharaoh ant colonies consists of several nests with no antagonistic behavior between them. Each colony contains workers, immature stages, numerous fertile queens, and intermittently, a few males. The development time from egg to adult is approximately 36 days depending on temperature and workers can live 9-10 weeks (Peacock and Baxter 1950).

Although it normally does not nest outdoors except in tropical climates, it has been reported to persist outdoors in temperate regions where the temperature is artificially maintained, such as refuse dumps (Kohn and Vlcek 1986). Nests are usually located in inaccessible areas such as interior wall voids, under or behind window sills, toilets, sinks, switch plates, lights, etc. and these locations can make control difficult. Generally, any area with warm temperatures and high humidity can suffice as a nest site (Edwards 1986). Common nest sites in north Florida are inside aluminum window and door frames. Also, in this area, Pharaoh ants have been found foraging both indoors and along the outdoor perimeter of buildings while in central and south Florida, foraging was observed further away from structures and nests were observed at the base of tree limbs.

Mating takes place within the nest (there are no mating flights) and new colonies arise from splitting of the main colony when workers move immatures and one or more queens to another location in the dwelling. However, it is not necessary for workers to include queens to start a new colony because they can simply move some brood and rear them to begin another colony. Only workers and brood need to survive to establish a colony (Peacock et al. 1955). Vail (unpublished) found that a new colony can be started with as little as 5 workers, 3 pupae, 19 larvae and 30 eggs. Reproduction by budding also reduces the antagonistic behavior between colonies allowing more cooperation and, because there is no territory to defend, larger densities may occur. Several factors can influence budding such as changes in the environment (temperature, moisture, and food resources), overcrowding, and the presence of certain insecticides (Edwards 1986, Green et al. 1954).

Pharaoh ants are omnivorous, feeding on almost any type of food and are quickly attracted to new food substances. In fact, they have been known to switch preferences for baits suggesting that they become satiated quickly to one

type of food substance (Edwards and Abraham 1990). In laboratory results, Williams (1990) indicated that the most attractive substances were lard, peanut butter oil, and honey. Workers follow paths along cracks, pipes or edges of structures, a behavior described by Klotz and Reid (1992) as structural guideline orientation. Once a food source is located, the worker returns to the nest laying down the trail pheromone, faranal, (Ritter et al. 1977) and follows a more direct route back to the nest indicating the possibility of using visual orientation. Foraging studies performed in a large building (7841 m²) indicated the maximum foraging distance to be 45 m and the average foraging distance to be 16.2 m (Vail and Williams 1994). For additional information on foraging by Pharaoh ants, see Sudd (1957, 1960).

CONTROL

Pharaoh ants can present many problems for the pest control industry because they can be very difficult to control. One reason is that nest sites or colonies are difficult to locate. If the colonies are not completely eliminated, reinfestations occur rapidly. Long term control can be very hard to maintain because of reinfestations and may require several return visits resulting in dissatisfied customers. Also, these ants require very small openings through which to enter and leave their nests and their habit of living in interior walls permits them to move throughout a building. These characteristics make control techniques utilizing sprays and dusts ineffective since these treatments only affect a small percentage of the workers that forage (Williams 1990) and will not result in elimination of the colonies. In fact, the use of sprays and dusts may also cause budding which may exacerbate the problem. Another problem is that colonies can survive for long periods without foraging workers (Kretzschmar and Brendt 1976) therefore, killing only foragers may give the false impression that the colonies have been eliminated. Also, the colonies are polygyne (there are more than one egg-laying queen present), thus, after a treatment the majority of queens may survive and continue to produce large numbers of eggs (Edwards 1986); and even if the queens do not survive, workers, as previously mentioned, can rear reproductives from existing brood. Finally, because of the many nest sites it inhabits complete insecticide coverage is difficult to obtain (Williams 1990). For a review of control methods, see Edwards (1986).

The control of a pest ant species such as Pharaoh ants generally relies on toxic baits which consist of a toxicant combined with an attractive food material. The effectiveness of this method depends upon the accessibility of a delayed-action toxicant so that foraging ants are not killed before they transport it back to the nest and share it with all colony members (Lofgren 1986). Several characteristics are important for a chemical to become useable in an ant bait. The chemicals must:

- a) exhibit delayed toxicity
- b) be effective over a wide dosage range
- c) be soluble in an attractive food material,

- d) lack repellency to the ants,
- e) be transferred readily from one ant to another during trophallaxis, and preferably
- f) exhibit low mammalian toxicity, and
- g) be environmentally safe.

The above criteria demonstrate the difficulty in discovering and developing chemicals for use in ant baits. When using a bait for the control of Pharaoh ants, there are several factors that should be considered.

- a) The bait should be stored in an area where its freshness will not be affected, for example, it should not be placed in an area where it will receive excessive moisture or dryness.
- b) The time of year that the bait is applied can be very important because extreme temperatures can reduce foraging.
- c) The mode of action of the active ingredient in the bait will affect its speed of action. For example, stomach poisons will take a week or more to cause a noticeable decline in the population while IGR's may take several weeks to months to affect the population.

Toxic baits, also can be combined with conventional applications of residual insecticides when a rapid reduction or elimination of foraging workers is needed as in sensitive areas such as surgery and neonatal care units in hospitals. However, care must be taken because the use of insecticidal sprays in hospitals is strictly regulated. It is very important to always apply the baits prior to (3-5 days) the application of sprays and dusts.

There are several active ingredients that are effective in toxic baits against Pharaoh ants. These include the metabolic inhibitors, hydramethylnon, sulfluramid, and several forms of boric acid (orthoboric acid, and sodium tetraborate decahydrate [borax]); the juvenile hormone analogues (JHA), methoprene, fenoxycarb, and pyriproxyfen; the reproductive inhibitor (RI), abamectin; and the chitin synthesis inhibitor (CSI), teflubenzuron. There are probably others that are also effective and are being developed for commercial use or will be in the future. Currently, the following chemicals are used in commercial baits: hydramethylnon (Maxforce Pharaoh Ant Killer, Clorox Co., Pleasanton, CA), sulfluramid (Raid Max Ant Bait, S. C. Johnson, Racine, Wisconsin, and Pro-Control, Micro-gen Equipment Corp., San Antonio, TX 78217), orthoboric acid (Drax Ant Kill Gel Waterbury Co. Inc., Waterbury, CT) and sodium tetraborate decahydrate [borax] (Terro Ant Killer II Senoret Chemical Co., St. Louis, Missouri) and the JHA, methoprene, (Pharoid, Zoecon Corp., Dallas, TX). Pharoid may no longer be commercially available.

Stomach poisons which are usually metabolic inhibitors work relatively fast compared to JHAs, RIs, and CSIs. Worker numbers are usually reduced in a few days and whole colony elimination can occur in just a few days to a few weeks. However, in some cases, stomach poisons work too quickly, eliminating

the worker force before the insecticide can be disbursed to the entire colony.

The JHAs, RIs, and CSIs act much slower than metabolic inhibitors because their affect is a disruption of vital processes such as metamorphosis, reproduction or chitin formation which occurs considerably slower than direct toxic action (worker mortality). For example, methoprene induces sterility in queens and disrupts the brood stages (Edwards 1975) but does not affect workers which continue to be present for weeks or months after treatment. Because the life span of a worker is approximately 9 - 10 weeks (Peacock and Baxter 1950), they may be seen long after the queens have discontinued egg-laying and the brood has died. The advantage of chemicals such as JHAs is that they are usually less toxic to veterbrates and more likely to be dispersed throughout the entire colony because they do not effect workers adversely. The obvious disadvantage with these compounds is their slow action in eliminating the pest problem.

Our laboratory has conducted tests with the JHAs, fenoxycarb, and pyriproxyfen, and the CSI, teflubenzuron against Pharaoh ants and all have shown to be excellent chemicals for use in baits. Fenoxycarb is already registered as a bait for the red imported fire ant, Solenopsis invicta in the USA and its registration is being pursued for use against other urban ants including the Pharaoh ant. Pyriproxyfen is also in the process of being registered for urban ants including Pharaoh ants. Teflubenzuron is not being considered for registration against ants at this time.

As mentioned, the discovery of compounds for use in baits against pest ants is difficult because of the need for a delayed-action chemical. The development of baits for use against ants began as an intensive effort by the USDA, Agricultural Research Service (ARS) in their search for delayed toxicants for use against the red imported fire ant, Solenopsis invicta. Since 1958, the USDA, ARS has evaluated more than 7100 compounds for delayed action against fire ants (Williams 1994). This effort resulted in the formation of requirements needed for an effective toxicant (Stringer et al. 1964) and to the development of laboratory and field bioassays that would clearly reveal these attributes.

LABORATORY EVALUATION OF CHEMICALS FOR BAITS

The majority of laboratory procedures developed for evaluating chemicals for use in baits against ants was originally developed for fire ants (Stringer et al. 1964, Lofgren et al. 1967, Levy et al. 1973, Banks et al. 1977, Williams et al. 1980, Williams 1983 and Banks and Lofgren 1991). Edwards (1975, 1986) and Edwards and Clark (1978) have described laboratory and field procedures for Pharaoh ants. Our procedures have been described recently (Williams 1990, Williams and Vail 1993, 1994) and they are as follows:

Preliminary laboratory tests were conducted against individual worker ants (20 workers per 30ml cup) or small colonies consisting of 3 queens, 0.2 ml of brood, and approximately 500 workers. A 0.5% and 1.0% solution of the candidate chemical in a water, sugar or oil formulation or as a formulated bait was provided to the ants. Baits without the chemical were used as controls. The test solution was offered to each colony for 72 hrs (3 days) for maximum distribution throughout the colony after which the bait was removed and the colony is fed the regular laboratory diet. Chemical toxicants or bait formulations showing promise in the preliminary tests were further tested at several concentrations against large laboratory colonies consisting of 100-200 queens, 7 g of brood, and 5,000-7,000 workers.

Weekly observations were made on the status of the colony (normal or abnormal), queens (size, whether or not they are laying eggs, and acting normal), type and quantity of brood, estimated worker numbers, obvious morphological anomalies and total mortality. The criteria used for efficacy were: (1) the total number of workers present and worker mortality, (2) the brood rating and brood mortality, and (3) queen death or cessation of eggs. In the small colonies, we also used the first appearance (time in weeks) of winged reproductives. Observations were continued until the colony died or completely recovered and returned to normal. The latter condition was considered to be in effect after the queens begin normal egg-laying, all stages of brood are present, and the amount of brood and worker numbers were equal to or greater than before treatment.

FIELD EVALUATION OF BAITS

The evaluation of baits against natural populations of the Pharaoh ant were conducted in infested buildings (homes, apartments, condominiums, etc). An initial survey of the ant population was conducted before the actual bait application by placing ≈ 1 g peanut butter on white cards (6.5 cm-7.5 cm) throughout the building. Survey cards were placed in areas where the ants forage. Normally 2-6 cards are placed in each room. All cards were left undisturbed for 2-2 1/2 hrs, then the number of worker ants on each card was counted, and the data recorded. The baits were formulated for ease of application. One week after the initial survey, all of the baits were applied. An untreated area was used as a control throughout study. Generally, bait applications of IGRs were made once per week for 2 wk while only one application was made for stomach poisons. The baits were placed in the same locations as the survey cards. Treatment efficacy was determined by comparing the worker ant population before treatment with that after treatment using the same procedure as the initial survey. Surveys after treatment were usually conducted at 2 wk intervals up to 12 wks and then every 4 wks thereafter until the population completely died out or began to recover; however, the survey schedule may vary depending on the study.

SOME RECENT RESEARCH AT USDA-ARS, GAINESVILLE, FL

In laboratory studies with Pharaoh ant colonies, more than 55 food substances were tested and the most attractive to workers were lard, peanut butter oil, and honey. In laboratory studies, multiple applications of baits were generally required for complete elimination of Pharaoh ant colonies using IGRs while only single applications were needed using stomach poisons. In studies against natural infestations of Pharaoh ants, baits containing 0.5% fenoxycarb and 0.5% and 1.0% pyriproxyfen provided control similar to that of commercially available baits. The effects of pyriproxyfen on laboratory colonies of Pharaoh ants were collapsed eggs, cessation of molting in the larval stages, and the formation of intermediate stages. In studies against natural infestations of Pharaoh ants, placement of Maxforce baits outside of buildings worked as well as placing baits both inside and outside the structures. In laboratory studies, 35 compounds were tested as repellents against Pharaoh ants and fire ants with a few showing potential against both pest species.

SUMMARY

The Pharaoh ant is a pest ant that occurs throughout much of the world. It is considered an urban pest because it invades dwellings such as houses, apartments, bakeries, hospitals, etc. Pharaoh ants are difficult to control because of their ability to reproduce by budding, initiation of new colonies without the presence of a queen, and their inaccessible nests. Current control techniques use toxic baits, dusts or sprays. Baits are the most effective and may contain stomach poisons (metabolic inhibitors), juvenile hormone analogues, reproductive inhibitors, or chitin synthesis inhibitors as the active ingredients. In addition to several commercial formulations available, the IGRs fenoxycarb and pyriproxyfen were tested against natural infestations of Pharaoh ants and gave excellent control.

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IMPLEMENTING COCKROACH IPM PROGRAMS

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ABSTRACT: In recent years, the interest in utilizing Integrated Pest Management (IPM) to control German cockroaches has dramatically increased. Public awareness and concern over the use of insecticides, increasing problems with insecticide resistance, and the continuing loss of our chemical arsenal to control cockroaches have stimulated research for new alternatives. The use of inorganic dusts and baits have proven to be highly successful in IPM programs. It is unlikely that cockroach control will ever be practiced without chemicals because of the need for eradication in many urban situations. However, it is clear that additional basic research and new pest management strategies will be necessary if we are to successfully control the German cockroach in the future.

KEYWORDS: German cockroach, *Blattella germanica*, integrated pest management

INTRODUCTION

In recent years, there has been an increasing awareness and interest in the use of Integrated Pest Management (IPM) in urban settings. An operational view to the implementing of cockroach IPM includes the following components: targeting the audience, targeting the pest, monitoring techniques, developing control strategies specific to the target pest, providing educational materials, and evaluating performance (Slater et al. 1979, Zungoli and Robinson 1986, Robinson and Zungoli 1994, Slater 1994).

Each of these aspects are extremely important in developing a complete program.

The concept of IPM dates back to the late 1950's and a monumental study conducted by Stern et al. (1959) and Stern and van den Bosch (1959) on the control of the spotted alfalfa aphid. This strategy is based on three fundamental philosophical concepts (Flint and van den Bosch 1981):

1. A conception of the managed resource as a component of a functioning ecosystem.
2. An understanding that the presence of an organism of pestiferous capacity does not necessarily constitute a pest problem.
3. An automatic consideration of all possible pest control options before any action is taken.

IPM incorporates the use of insecticides, but only after a systematic evaluation of the problem has occurred and all other options have been considered.

Some of apparent similarities and differences between agricultural and urban IPM are listed in Table 1. With the reduced reliance on pesticides, there is an increased emphasis on exploiting key environmental factors that impinge on the pest such as parasites or predators or targeting weak links in the life cycle. For example, in IPM programs to control cat flea, *Ctenocephalides felis* (Bouche), the sensitivity of the egg and larval stages to desiccation and insect growth regulators (IGRs) and critical nutritional requirements can be exploited to reduce the need for extensive applications of conventional insecticides in indoor environments (Dryden and Rust 1994). The adult male might be considered the weak link in the life cycle of the German cockroach, *Blattella germanica* (L.). When deprived of food and water, adult males died 4 days earlier than did adult females (Willis and Lewis 1957). In addition, Ross (1978) found that maximum male competitiveness for mates peaks in weeks 2 to 3 of adulthood. However, it might be argued that middle- to late-instar nymphs are also a vulnerable stage because of their mobility. Studies by Ross et al. (1984) indicated that these instars are the most mobile stage. Consequently, they might be more likely encounter traps, baits or residual insecticide deposits. In fact, female late-instar nymphs also ingested more bait containing IGR than did males (Ross and Cochran 1990).

TABLE 1-- Similarities and differences between agricultural and urban IPM programs.

Similarities	Differences in Urban systems
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1. Reduce pesticide use	1. Eradication is often a goal
2. Exploit environmental factors	2. Lack of natural enemies to release
3. Target weak links of the life cycle	3. The pest is often the problem
4. Monitoring	4. Aesthetic Injury Levels
	5. Reliance on long lasting residual insecticides

Monitoring is a key element of IPM programs (Flint and van den Bosch 1981, Owens 1994, Robinson and Zungoli 1994). An active monitoring program not only permits the detection of the pest, but can serve as the basis for implementing control measures. It is the vital element in evaluating the success of any IPM program.

One of the important philosophical differences between agricultural and urban IPM is that eradication is never a goal in agricultural systems. All of the elements of the system are managed, but the goal is never to eradicate the pest. On the contrary, in urban situations the primary objective is often the eradication or elimination of the pest, especially German cockroaches, cat fleas and termites. The mere presence of these insects is often the problem in urban settings. A survey by Wood et al. (1981) indicated that tenants would probably not consider a pest management program successful unless the number of cockroaches seen per day was at least less than five. Even 47% of the respondents felt that two cockroaches per day was a problem. Tenants often equate cockroaches with other negative aspects in their lives. Olkowski (1974) first purposed the concept of Aesthetic Injury Level (AIL) to address situations where economic damage caused by arthropods may not be directly measurable. As Zungoli and Robinson (1984) indicate AIL is a variable concept, speculating that as infestation level declines, tolerance of cockroaches will also decline. Programs will need to reflect the attitudes of the target audience.

In agricultural settings, the presence of a pest may not cause an economic impact. The concept of Economic Injury Levels (E.I.L.) has been developed to deal with situations where the cost of control may be more than the loss incurred (Flint and van den Bosch 1981). In order to prevent economic losses, a second population parameter Economic Threshold (E.T.) or "control action threshold" has been devised. This threshold indicates to the pest manager when it is necessary to act to prevent economic losses (Fig. 1). In urban settings, the A.I.L. replaces the Economic Threshold with

most structural indoor pests. Only on rare occasion can we actually assess the economic damage caused by ants, cockroaches, and fleas.

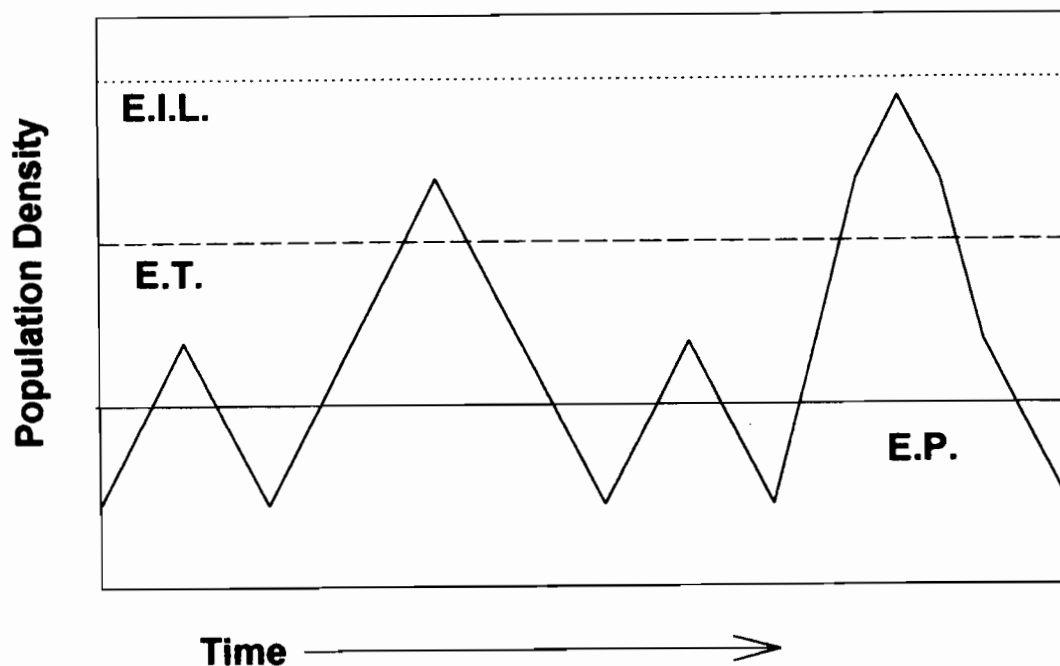


Fig. 1. Equilibrium position (E.P.) of the pest population is close to the Economic Injury Level (E.I.L.) requiring frequent pest management action. E.T. - economic threshold. In urban settings the Aesthetic Injury Level (A.I.L.) replaces the E.T. (adapted from Flint and van den Bosch 1981).

Another dramatic and fundamental difference between agricultural and urban systems is the manner in which pesticides are applied. In agriculture, insecticides are frequently applied to prevent feeding damage or kill various stages on contact. Short residual activity is generally very desirable permitting reentry into the field and harvesting of the crop. Urban strategies against ants, cockroaches, and termites have often emphasized the use of insecticides that provide long-residual deposits capable of killing insects even months or years after application. Consequently, the amounts and frequency of insecticide applications in urban settings can be substantial.

What are the costs of implementing cockroach IPM programs in apartments, single family dwellings, restaurants, schools, etc.? Is IPM widely practiced by pest control companies? These questions were asked of two technical directors of large pest control firms in southern California. Their responses were quite different and very interesting. One director felt that at least in his company very little IPM for German cockroach control was done. Quality service was hard to sell because it was labor intensive and required

increased level of professionalism. Most accounts could simply not afford the necessary expenses of implementing an urban IPM program. The other director has seen dramatic increases in the demand for IPM services, especially for commercial accounts. The company policy of selling the customer on the advantages of IPM for cockroach control certainly contributed to its increased use.

Both felt that it is important to understand the customer's real and perceived problems and expectations. For example, many customers believe that when they purchase pest control services, it includes ants, rodents, spiders, and crickets in addition to cockroaches. Successful IPM accounts are those in which the customer is actively involved with the pest control firm. As one director stated, "Complacent customers end up with a mediocre service at best." Education is critical component, each customer being provided handouts, brochures, pamphlets and training programs. Customers are requested to prepare areas for treatment, improve sanitation, shut down the facility and attend special seminars and presentations. Urban IPM is a two-way street; as service is rendered, the customer has to take part and become involved. Wood (1980) considered this to be one his three "roach laws" regarding pest management in public housing. Clearly IPM services are economically feasible, but many changes in the industry and public will be necessary before it is ever fully implemented.

After all the inspections, monitoring, and interaction with the customer, the implementation of a control strategy remains. Do we have the necessary tools to achieve IPM of German cockroaches? The following review is intended to highlight some proven strategies and indicate where research is still needed.

The incorporation of inorganic dusts into control programs, especially when applied to voids to reduce cockroach harborage, has been extremely successful (as reviewed by Ebeling 1994, Slater 1994). The insecticidal activity of inorganic dusts can be categorized according to their mode of action as desiccants or internal toxicants. Boric acid acts as an internal poison (Ebeling et al. 1975). Boric acid powder does not absorb cuticular waxes resulting in increased water loss. Desiccants such as silica aerogel remove cuticular lipids and result in rapid water loss and mortality (Table 2). Another frequent misconception is that boric acid acts solely as a stomach or feeding poison. However, the time required to produce 100% kill of American cockroaches with and without sealed mouthparts was 89 and 68 hours, respectively. Penetration of the integument was confirmed by a boric acid flame test (Ebeling et al. 1975).

TABLE 2-- The rate of water loss of adult male German cockroaches confined to dust deposits (Ebeling et al. 1975).

Contact	Weight Loss	Water Loss
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Powder ^a	(hours)	(%)	(%)
Boric acid	3	0.8	0.5
	6	2.5	1.6
Gardona	3	6.3	4.1
	6	11.9	7.8
SG-68	3	22.0	14.5
	6	33.0	21.7
Control	3	2.5	1.6
	6	4.7	3.1

^a Boric acid tech. powder passed thorough a 325-mesh screen; SG-68 (Dried 68) an amorphous silica aerogel; 96% tech. Gardona [2-chloro-1-(2,4,-trichlorophenyl) vivnyl dimethyl phosphate].

Certain powders especially desiccants such as silica aerogel are highly repellent and cockroaches avoid contacting deposits (Ebeling et al. 1966). Some of the advantages and disadvantages to applying repellent powders are listed in Table 4. At the time of construction, the application of highly repellent powders has been extremely effective in preventing cockroach infestations from becoming established (Moore 1973).

TABLE 4-- The use of repellent chemicals in German cockroach IPM programs (Reierson unpubl. data).

Advantages

- 1). Protect specific sites in a structure
- 2). Prevent wall and cabinet voids from serving as harborage sites
- 3). Inhibit unrestricted movement of cockroaches
- 4). Minimal mammalian toxicity with many inorganic desiccants

Disadvantages

- 1). Cockroaches learn to avoid deposits
- 2). Poor knockdown of cockroaches because of short contact
- 3). Increased cockroach movement into untreated areas

Residual deposits of insecticides will continue to play an extremely important role in cockroach IPM programs. Both abiotic and biotic factors can dramatically affect the activity of residual insecticide deposits. Ebeling and Wagner (1965) demonstrated the effect of relative humidity on the volatilization of diazinon on various surfaces against adult red flour beetles, *Tribolium castaneum* (Herbst). On porous and hygroscopic surfaces such as paper or wood, the availability of the diazinon increased at high RHs. On lipophilic surfaces such as beeswax, leaves, and painted wood, the availability decreased at high RH's. Similarly, Rust and Reiersen (1988) and Braness (1990) have shown that contaminants such as grease, oils, and even cockroach fecal material decreases the activity of pyrethroids. As little as 6.6 g of corn oil per square meter decreased the activity of pyrethroids up to six-fold. Certain surfaces such as vinyl tile or latex painted wood can also dramatically reduce the activity by absorbing the insecticide (Table 5).

TABLE 5-- Effect of substrates on the insecticidal activity of cypermethrin and chlorpyrifos against adult male German cockroaches in brief exposure tests (Rust unpubl.).

Insecticide	Exposure (min)	% Mortality 24-h post exposure		
		Wood	Vinyl Tile	Latex
Cypermethrin 0.1%	1	70	70	20
	5	80	90	20
	30	100	100	50
	60	100	100	30
Chlorpyrifos 0.5%	1	60	80	0
	5	70	60	20
	30	100	90	20
	60	100	60	20

Another abiotic factor that dramatically influences the activity of residual deposits is temperature (Rust 1994). Certain insecticides such as DDT, fenvalerate, permethrin, and pyrethrin exhibit an inverse temperature relationship. As the temperature of the deposit decreases, the insecticidal activity increases (Table 6). Consequently, it is important to avoid using residual insecticides with inverse temperature relationships in hot areas around dishwashers, stoves, heating units, machines, etc. These insecticides might be excellent barriers outdoors, especially at cooler evening temperatures.

TABLE 6-- Activity of selected pyrethroids against adult male *Blattella germanica* (L.) in continuous exposure tests (Rust unpubl.).

Insecticide	A.I./m ² 32.2°/15.5°	<u>Time (hr) to 90% knockdown</u>		ratio
		32.2°C	15.5°C	
Cyfluthrin	3.93	0.5	0.5	1.0
	0.79	5.4	5.0	1.1
Cypermethrin	3.93	2.8	0.8	3.5
	0.79	(62%)	0.6	
Fenvalerate	3.93	8.3	7.8	1.1
	0.79	(59%)	(90%)	

The two biotic factors that have the greatest impact on the performance of residual insecticides deposits are repellency and insecticide resistance. Ebeling et al. (1967) found a inverse relationship between the toxicity of residual deposits and the efficacy in choice boxes. However, this relationship is not applicable to some wettable powder formulations of pyrethroids (Rust 1994) which kill cockroaches with as short as 5-second exposures (Schneider and Bennett 1985). Recent studies by Wooster and Ross (1989) and Ross (1992) show that vapors of propoxur and pyrethroids repelled cockroaches and induced more rapid dispersal.

To combat insecticide resistance three following principal strategies have been proposed: management by moderation, management by saturation, and management by multiple attack (Georghiou 1983).

Management by moderation incorporates low dosages, less frequent applications, short-lived insecticides, localized applications, preservation of untreated areas, and selection against adults. It is very unlikely that many of these practices would be utilized to control cockroaches indoors. Apartments infested with German cockroaches with a history of control failures were treated with large dosages of chlorpyrifos and diazinon to determine if management by saturation was feasible. Apartments were thoroughly treated with 0.75% chlorpyrifos 4E sprays, 1% chlorpyrifos dust, and 0.75% chlorpyrifos spray and 1% chlorpyrifos dust. Another group of apartments were treated with 1% diazinon 4E, 1% diazinon 2FM or 2.5% diazinon 2FM sprays. Even the maximum treatment rates only provided about 80% reductions in trap counts at week 8. It is unlikely that management by saturation is practical means of controlling German cockroaches, especially populations that might have been previously treated.

Several multiple attack strategies show some promise. Cochran (1987a) was able to use synergists such as piperonyl butoxide (PBO) and MGK 264 to effectively reduce the resistance ratios of several field strains of German cockroach to bendiocarb and pyrethrin. While synergists have negated resistance to pyrethrins, resistance to allethrin was not affected (Cochran 1987b). Unfortunately, the addition of pyrethrins and PBO to bendiocarb results in very repellent residual deposits (Table 7). The possible use of synergist or mixtures of insecticides will be greatly influenced by repellency of the materials used and the behavior of field populations of cockroaches. Our options and combinations will be extremely limited.

TABLE 7-- Efficacy of three formulation of bendiocarb against a susceptible laboratory and field-collected strain of German cockroach in choice boxes (Rust and Reiersen unpubl.)

Treatment ^a	Strain ^b	Percent dead at day		
		1	7	14
1% dust	sus	5	60	95
	fc	0	0	10
0.5% spray	sus	2	40	67
	fc	3	35	50
0.25% spray + pyrethrins + PBO	sus	0	15	22
	fc	3	23	28

^aApproximately 10cc of dust or 3 ml of spray applied per 464 cm².

^bSus- laboratory susceptible strain; fc- field-collected strain.

Another strategy involving management by multiple attack is the idea of rotating unrelated insecticides. The concept is based on the assumption that the frequency of resistant alleles in the population to the first insecticide used will decrease when a second structurally and metabolically unrelated insecticide is applied. It is assumed that selection for resistance reduces biological fitness (i.e. that there is a "cost" for resistance) so that when selection pressure is removed the population gradually reverts to the susceptible genotype. However, we know very little about the biological fitness or behavior of field-collected strains of German cockroaches. Rotations will probably be effective if cross-resistance does not develop between the insecticides selected for the rotation.

Cochran (1990) has proposed two rotational schemes for the control of *B. germanica* depending upon whether there have been any control failures (Table 8). The interval between treatments ensures that only 1 or 2 generations will be selected with the same insecticide, consequently reducing the amount of selection pressure. From a biological standpoint, the proposed rotations seem reasonable. However, the major challenge for the professional pest control operator will be deciding which of the various insecticides and formulations to rotate. Brenner et al. (1988) reported on several rotational schemes using acephate, chlorpyrifos, fenoxycarb, fenvalerate, and synergized pyrethrins. Monthly treatments of acephate provided 44-83% reductions in trap counts for the first 10 months, however in the last two months the reductions were only 46.5 and 30.9%. The addition of 0.5 % synergized pyrethrins every six months to acephate did not significantly improve control, reductions being 44.0 and 58.6% in the last two months. In apartments treated for five consecutive months with fenvalerate or for consecutive applications of chlorpyrifos and 1 application of fenvalerate and followed by seven consecutive monthly applications of acephate, there was no significant reduction in trap counts at 1 year compared with a monthly application of acephate. The only treatment scheme that provided significant reductions at 1 year incorporated a rotation of either fenvalerate and fenoxycarb for 5 months and acephate and fenoxycarb for 7 months. This study highlights the problems associated with rotating just any pyrethroid or organophosphate.

TABLE 8-- Rotational strategies proposed by Cochran (1990).

No Treatment Failures	Prior Treatment failures
-----------------------	--------------------------

1 mo. residual pyrethroid	1 mo. bait
7 mo. organophosphate or carbamate	7 mo. organophosphate or carbamate
13 mo. bait	13 mo. residual pyrethroid
19 mo. repeat sequence	19 mo. repeat sequence

Research is ongoing into the use of alternative technologies such as nematodes, fungi, modified atmospheres, and heat sterilization (Gold 1994). Preliminary studies with the modified atmospheres and heat treatments look very promising. Incorporation of these alternative strategies should assist in reducing the increasing problems associated with insecticide resistance. In the future we will have to rely even more heavily on the alternative pest control technologies if we are to have viable Integrated Pest management programs for cockroach control.

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ABSTRACTS OF PRESENTED PAPERS

Termites - Jack Ryder, Moderator

Cockroaches - Pat Zungoli, Moderator

Fleas, Ants, Ticks and other Urban Pests - Nancy Hinkle, Moderator

A METHOD FOR DEFINING THE TERMITICIDE BARRIER: RESIDUE AND BIOASSAY ANALYSIS TO ASSESS SOIL PENETRATION OF TERMITICIDES

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REFERENCE: Barlow, R. A. and Nonggang Bao. 1994. A method for defining the termiticide barrier: Residue and bioassay analysis to assess soil penetration. National Conference on Urban Entomology 1994.

ABSTRACT: Protecting structures from subterranean termites includes the application of liquid termiticide to the soil adjacent to the footing inside and outside the structure. The effectiveness of the termiticide is linked to the penetration in the soil and repellent or toxic activity of the soil residue. The effective threshold for termite control with modern termiticides ranges from 1 to 100 ppm. The method currently used to evaluate termiticide barriers is a 5 cm uniform mix of soil and termiticide.

The objectives of this research were to evaluate the soil penetration of two formulations of the pyrethroid deltamethrin by 1) analysis of deltamethrin residue at three depths (0-1, 2-3, 4-5 cm) in treated soil, and 2) bioassay of core samples of treated soil using soldier and worker subterranean termites. Deltamethrin (0.1% AI) EC and SC were applied at the rate of 4 liters per sq meter to sandy loam soil. After 24 h four replicates of three 5 cm core samples were taken randomly from each site. Two core samples were used for the bioassay and one for the residue analysis.

Results indicate that the deltamethrin formulations penetrated to a depth of 2-3 cm into the soil. No deltamethrin was detected below the 3 cm soil depth. In the bioassay test, the tunneling activity of the worker termites did not exceed the 2-3 cm depth of soil, which was consistent with the depth of residue detected in the soil core evaluations.

KEYWORDS: Termiticide, bioassay, soil penetration, deltamethrin

THE BEHAVIORAL RESPONSES OF THE WESTERN DRYWOOD TERMITE *Incisitermes minor* (HAGEN) TO A TEMPERATURE GRADIENT

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REFERENCE: Cabrera, B.J. and M.K. Rust. 1994. The behavioral responses of the western drywood termite, *Incisitermes minor*, to a temperature gradient. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: A system was devised to study the behavior of *I. minor* nymphs on temperature gradients. The test apparatus consisted of a piece of balsa wood placed on an aluminum bar that was heated or chilled at one end to produce a gradient. Controls did not have a gradient. The wood was covered by a plexiglass dome and air at either 10, 30 or 50% RH was pumped into the arena. The behaviors of 15 nymphs were recorded for 5 min every hour for 24 hours.

I. minor nymphs avoided temperatures above 45°C and below 12°C, formed aggregations away from the hottest or coldest temperatures, and also aggregated in the controls. The distributions of termites on heated or cold gradients were significantly different from the controls and were not affected by RH. Aggregations formed fastest on heated gradients and were found at slightly lower temperatures at 10% RH than at 30 or 50% RH. Individual and group trail-following behaviors provide evidence for the use of a trail pheromone.

Temperatures within various wood members of an attic often exceeded temperatures that the termites avoided on the gradients. This information, together with the observed behaviors, provides evidence that *I. minor* colonies may relocate within structures in response to high or low gallery temperatures. This may be of particular importance for inspections and spot treatments of *I. minor* infestations.

KEYWORDS: Behavior, *Incisitermes minor*, temperature gradient.

FIELD EVALUATIONS USING A TERMITE BAIT CONTAINING HEXAFLUMURON IN THE SOUTHEAST U.S.

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REFERENCE: DeMark, J. J., P. A. Zungoli, E. P. Benson, and B. M. Kard. 1994. Field evaluations using a termite bait containing hexaflumuron in the southeast U.S. Proceedings of the National Conference on Urban Entomology, 1994.

ABSTRACT: Research sites in Auburn, Alabama, Clemson, South Carolina, and Gulfport, Mississippi were characterized for termite activity and subsequently baited with a bait containing the IGR hexaflumuron. Among the three locations, six separate colonies were baited. The species baited included the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), the southeastern subterranean termite *Reticulitermes virginicus* Banks, and the Formosan subterranean termite, *Coptotermes formosanus* Shiraki.

Results three months post-baiting have shown that the colonies have been eliminated or progressing toward elimination with the hexaflumuron bait. Monthly wood consumption rates in traps at the baited colonies gradually dropped to zero (grams/trap/day) as the baiting continued. These results along with earlier results reported by Nan-Yao Su at the University of Florida have demonstrated hexaflumuron to be a very effective termite bait.

KEYWORDS: Hexaflumuron, efficacy, bait, subterranean termites.

DATA FROM THE LABORATORY AND FIELD PROVIDE EVIDENCE THAT RAINFALL CAN EFFECT SUBTERRANEAN TERMITE POPULATIONS

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REFERENCE: Forschler, Brian T. and M. L. Townsend. 1994. Data from the laboratory and field provide evidence that rainfall can effect subterranean termite populations. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Laboratory tests involving termite response to rising water levels demonstrated that subterranean termites (*Reticulitermes* sp) do not try to escape being submerged by water. Other studies provided LT_{50} 's of 2.3 days for *Reticulitermes flavipes* and 1.1 days for *R. virginicus* termites that were completely submerged in water. These data suggest that termites, in the field, escape drowning not by seeking higher ground but by entering a quiescence state when confronted with water in their subterranean habitat. Under normal rainfall conditions, water should move through the soil profile within several hours. If this does not occur, as was the case in the winter 1992, then high mortality could result. In the summer of 1992, we characterized the foraging populations of six subterranean termite colonies using the triple mark-recapture technique. These colonies averaged $436,398 \pm 660,129$ (range 1,759,678 - 14,556) foraging termites per colony. In the spring of 1993, these same colonies were recharacterized and their populations averaged $39,515 \pm 45,056$ (range 128,000 - 970) foraging termites per colony. This represents a 91% reduction in the average foraging populations for these colonies. We believe these population reductions were a result of the heavy rainfall in central Georgia during the winter of 1992. Rainfall for the months of November and December was 22.7 mm above normal according to the Georgia Automated Environmental Monitoring Network (GAEMN) weather data. During November there were two periods when rain fell 6 out of 7 days. In addition, at the end of December it rained 11 out of 16 days which included two periods of 4 consecutive days.

KEY WORDS: population estimates, rainfall, drowning, behavior.

EVALUATION OF VENTILATION PROCEDURES USED IN METHYL BROMIDE AND SULFURYL FLUORIDE FUMIGATIONS FOR DRYWOOD TERMITES

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Reference: Gold, R. E. and H. N. Howell, Jr. 1994. Evaluation of ventilation procedures used in methyl bromide and sulfuryl fluoride fumigations for drywood termites. Proceedings of The National Conference on Urban Entomology.

ABSTRACT:

Methyl bromide (Meth-O-Gas®) and sulfuryl fluoride (Vikane®) were used in tests which evaluated ventilation (clearance) procedures. The same 517 m³ home was fumigated a total of 12 times in these replicated studies. Experimental treatments were: fumigants (two), open ventilation, and closed ventilation. Each treatment was replicated three times. Fumigant concentrations were monitored in five locations including: living space within the house, attic, closed bathroom wall cabinet, within an interior wall void and exterior to the house. Monitoring was done with appropriate Kitagawa 578B detector tubes, Fumiscope Model E-V and Interscan Gas Analyzer.

Results indicated that "clearance" for Vikane® at 5 ppm was attained within 2 hrs as compared to methyl bromide at 3 ppm which took 4.5 hrs under "open" conditions. Under "closed" conditions, it took a mean of 3.3 hrs to clear Vikane® and 10 hrs to clear methyl bromide for interior wall voids. Both fumigants are equal in efficacy and time required for application and for the gas to reach equilibrium within the tarped structure. It was concluded that no complicated or sophisticated aeration schemes are required to achieve clearance as long as interior wall void concentrations are below the allowed fumigant levels.

KEYWORDS: Fumigation, methyl bromide, sulfuryl fluoride, drywood termites

**ASPECTS OF A RECENTLY ESTABLISHED POPULATION OF THE
FORMOSAN TERMITE, *COPTOTERMES FORMOSANUS*, IN SOUTHERN
CALIFORNIA**

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REFERENCE: Haagsma, K., M.K. Rust and D.A. Reiersen. 1994. Aspects of a recently established population of the Formosan termite, *Coptotermes formosanus*, in southern California. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: A population of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, was detected in a residential area of La Mesa, San Diego Co., California, in February 1992. Apparently introduced in wooden articles transported from Hawaii 11 years ago, the termites have been detected in soil, trees, structures, and wooden ornamental landscaping over an area of approximately 8000 square feet.

In June, 1992, a wooden stake monitoring system was installed over the suspected area of infestation. Stake monitoring has continued monthly, in addition to the installation of permanent monitoring stations (traps). To date, approximately 4% of the 1000 stakes placed on 16 properties have any evidence of attack by *C. formosanus*. Trap collections in 1992 and 1993 suggest termite activity in terms of the amount of feeding and the number of termites present at the traps is greatest in the months of March to May.

Alates swarmed from the beginning of June to the end of August, with the large flight occurring mid-June. Alates were found up to 3/16 of a mile away, suggesting further infestation in this area by *C. formosanus* may be a real possibility.

Currently, we are studying the effects of the introduction of a slow-acting toxicant bait at the site as a possible method of complete eradication of this population.

KEYWORDS: *Coptotermes*, foraging, baiting, control.

DISPERSION OF DURSBAN® TC IN SILTY CLAY AND LOAMY SAND SOILS AFTER RODDING APPLICATIONS

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REFERENCE: Kamble, S.T. and R.W.Davis. 1994. Dispersion of Dursban® TC in silty clay and loamy sand soils after rodding applications. Proceeding of The National Conference on Urban Entomology. 1994.

ABSTRACT: The dispersion of chlorpyrifos (Dursban® TC) rodded in clay and sandy soils to control subterranean termites was determined. The 42 units (each, 0.31 X 0.76 X 1.22 m) were constructed along a 26.8 X 1.52 X 1.22 m trench. The units were filled with silty clay or loamy sand soil. Chlorpyrifos 1% (AI) was injected into the soil with a B&G 1.22 m rod (equipped with 15.2 cm straight single bore or lateral flat fan tip). Chlorpyrifos was applied at 3.03, 6.06 or 9.09 L under 206.85 or 344.75 KPa per rodding point. Each of the 14 treatments had 3 replications. Hydraulic soil sampler was used to remove 4 soil cores (each, 5.08 cm dia. X 1.22 m) from each unit. Cores, 1, 2, 3 and 4 were at 0.0, 10.16, 20.32 and 30.48 cm from the rodding point, respectively. Each of 4 subsamples (30.48 cm)/core was placed in ziploc bags and stored at -20 °C. Chlorpyrifos from each soil sample was extracted and analyzed with a GC equipped with TSD. All data were analyzed by Proc GLM: ANOVA.

According to data, the lateral flat fan tip yielded more lateral dispersion of chlorpyrifos in clay and sandy soils than the straight bore tip. The termiticide quantities injected per hole did not significantly differ either in lateral or vertical dispersion of chlorpyrifos adequate to control termites (>4 ppm). Two pressures also had no significant effects on lateral or vertical distribution of chlorpyrifos. Chlorpyrifos >4 ppm was within 10 cm (horizontally) of the rodding point at soil depths upto 91.6 cm, and within 30.5 cm (horizontally) from the rodding point at soil depths from 91.7 to 122.0 cm.

KEYWORDS: Chlorpyrifos, dispersion, soil, termites, fate.

TERMITICIDE DEGRADATION AND EFFICACY FIELD TESTS

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REFERENCE: Kard, Bradford M. 1994. Termiticide degradation and efficacy field tests. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Degradation rates and efficacy of marketed termiticides are currently being studied. To evaluate degradation, soil was treated at lowest label rates (1990), and placed in trenches along the inside and outside of simulated concrete foundation walls. For residue analyses, soil samples were collected after 1, 30, 60, 120, 180, 240, and 360 days, and again at 2 and 3 years after treatment. For currently marketed termiticides, mean ppm \pm SD after 1 day, and 1, 2, and 3 years respectively, were: Dursban TC (1.0% AI rate), 924 \pm 192, 784 \pm 139, 584 \pm 129, 469 \pm 69; Demon TC (0.25%), 430 \pm 109, 128 \pm 42, 64 \pm 21, 40 \pm 18; Prevail FT (0.30%), 353 \pm 57, 158 \pm 17, 72 \pm 21, 61 \pm 9; Dagnet FT (0.50%), 471 \pm 127, 506 \pm 20, 202 \pm 44, 176 \pm 35; Torpedo (0.50%), 591 \pm 213, 428 \pm 39, 182 \pm 39, 179 \pm 39; Tribute (0.50%), 681 \pm 255, 868 \pm 101, 298 \pm 57, 171 \pm 39; water controls (0.0%), 0.0 \pm 0.0. Initial AI recoveries were within 95%+ CL of theoretical ppm.

Years of 100% control of subterranean termites (through 1993) provided by termiticides applied at highest label rates to soil under concrete slabs in four primary test sites (FL, AZ, MS, SC) are: chlorpyrifos 1.0% (Dursban TC; Equity), 6-12 years (1971 four-site test), 21 years (1967 Mississippi test); cypermethrin 0.50% (Demon TC, Prevail FT), 4-11+ years; permethrin 1.0% (Dagnet FT), 5-15+ years, (Torpedo), 3-13+ years; fenvalerate 1.0% (Tribute), 6-12 years; bifenthrin 0.125% (Biflex TC), 2-7+ years.

KEYWORDS: Degradation, efficacy, termites, termiticide.

BAITING EFFICIENCY USING A SELF-RECRUITING PROCEDURE FOR POPULATION REDUCTION OF SUBTERRANEAN TERMITES

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REFERENCE: Nan-Yao Su. 1994. Baiting efficiency using a self-recruiting procedure for population reduction of subterranean termites. Proceedings of the National Conference on Urban Entomology, 1994.

ABSTRACT: The baiting procedure which incorporated a matrix containing a chitin synthesis inhibitor, hexaflumuron, contained two basic elements; monitoring and baiting. Wooden stakes were first driven into soil to detect the presence of termites. Bait tubes were placed in soil where termites were detected. A *self-recruiting* procedure, in which termites collected from the detection stakes were forced to tunneled through the matrix in the bait tubes, significantly increased bait intake by termites.

KEYWORD: Termite bait, population management, self-recruitment, Formosan subterranean termite, eastern subterranean termite

FOAM: STRUCTURE AND ADVANTAGES IN TERMITE CONTROL

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REFERENCE: Tiernan, B. H. 1994. Foam: Structure and Advantages in Termite Control. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: The original formal attempts to study foam began in the 1800's. The studies were initially determined necessary because of the industrial need to reduce or control unwanted foams. After initial studies were developed, it became apparent to the investigator that foams are quite different - one from the other.

Most foams are entirely unfit for the purpose of transport and deposition of termiticides.

There are four basic qualifiers that, when recognized and addressed, can aid the formulator and thus the user of foams in selecting a suitable foam for termite control. These qualifiers are stability, drainage rate, expansion ratio, and spontaneity. A fifth property will be introduced in this presentation: flowability.

Why use foam? What are its advantages? Will it help control termites? How foam can be part of an IPM program.

KEYWORDS: FOAM, TERMITES, FLOWABILITY, STRUCTURE

INTEGRATION OF SPATIAL STATISTICS AND PROBABILITY CONTOURS IN DEVELOPING A "PRECISION TARGETING" COCKROACH PEST MANAGEMENT PLAN FOR BIOLOGICALLY-SENSITIVE FACILITIES

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REFERENCE: Brenner, R. J. and M. J. Hayes. 1994. Integration of Spatial Statistics and Probability Contours in Developing a "Precision Targeting" Cockroach Pest Management Plan for Biologically-Sensitive Facilities, Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: A cockroach management plan was developed for the Caribbean Fruit Fly Mass Rearing Facilities that uses spatial statistics and contour maps to estimate total population distribution of *Periplaneta australasiae* with precision, so that interventions are minimal and focused. Baited traps (53) were used for assessing spatial continuity in the structure of 10,500 sq. ft. From these data, probability contours are developed that provide the probability at any location of obtaining counts above a given threshold. In practice, this becomes the surveillance map for periodic trapping and inspection, and precision targeting. Spatial analysis revealed principally 2 areas of infestation by adult cockroaches, primarily inside the hollow metal doors that developed rust holes in this environment of 85% relative humidity. A separate area of infestation by immatures was confined in one room where nymphs were living inside hollow metal racks used to hold rearing trays. Expansive urethane foam was injected into the handle-access hole to deny access. A specially formulated toxic bait (0.5% chlorpyrifos) that is temperature- and humidity-responsive was used to eliminate residual and immigrant cockroaches. Bait stations were left in place only overnight during 7-14 days. In subsequent trapping, no cockroaches were found. The *objective* precision inherent in these techniques provides strong continuity from sampling period to sampling period -- regardless of who conducts the trapping. It is anticipated that such strategies will be transferred to health-care and food-preparation facilities.

KEYWORDS: *Periplaneta*, spatial statistics, precision targeting, bait, cockroach

ORAL TOXICITY AND REPELLENCY OF BORATES TO GERMAN COCKROACHES

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REFERENCE: Koehler, P. G., Strong, C. A., and Patterson, R. S. 1994. Oral toxicity and repellency of borates to German cockroaches. Proceedings of the National Conference on Urban Entomology, 1994.

ABSTRACT: The oral toxicities of boric acid and disodium octaborate tetrahydrate (DSOBTH) in wet-mixed, dry-mixed, and water solution baits were determined for German cockroaches, *Blattella germanica* L., in choice and nonchoice experiments. In dry-mixed, nonchoice bait tests, all cockroaches died within 1 wk. The relative orders of the LT_{50} s for boric acid and DSOBTH were 6.25% > 12.5% > 25% \geq 50% in nonchoice tests. In choice tests, the order of LT_{50} s of boric acid and DSOBTH were 6.25% = 12.5% > 25% = 50% and 25% > 12.5% > 50% > 25%, respectively. The differences between the LT_{50} s of the nonchoice and choice tests indicate repellency of the toxicants. Most German cockroaches died in 3-6 d in wet-mixed, nonchoice tests, but all cockroaches survived the wet-mixed choice tests except at the lowest concentration (6.25%) of boric acid, indicating repellency. In water-based solution, nonchoice tests, all cockroaches died in 5 d. In choice tests with boric acid, there was no increase in mortality at concentrations above 1%. Choice:nonchoice ratios indicated no repellency of water-based solutions.

KEYWORDS: *Blattella germanica*, disodium octaborate tetrahydrate, boric acid

**REPRODUCTIVE SUCCESS OF SEXUALLY AND ASEXUALLY
PRODUCED FEMALE BROWN COCKROACHES (*Periplaneta
brunnea* BURMEISTER).**

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REFERENCE: Luhring, K. A. and P. A. Zungoli. 1994. Reproductive success of sexually and asexually produced female brown cockroaches (*Periplaneta brunnea* Burmeister). Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Female brown cockroaches are capable of producing viable offspring parthenogenetically. We compared the reproductive success of asexual and sexual daughters during both sexual and parthenogenetic reproduction. To compare the females during sexual reproduction, we housed the females with a male immediately after the female molted. To compare the females during parthenogenetic reproduction, we allowed the females to produce 10 oothecae parthenogenetically. We measured the total number and the viability of the oothecae produced, the total number of nymphs, time to produce the oothecae, mean number of nymphs to hatch from each ootheca, and the developmental status of the unclosed embryos within an ootheca.

The reproductive success of the sexual or asexual daughters did not differ during sexual reproduction. However, during parthenogenetic reproduction, the asexual daughters were more successful. They produced more viable oothecae, and more nymphs during this time period than did the females that were produced sexually.

Keywords: Parthenogenesis, reproduction, *Periplaneta brunnea*

FACTORS INFLUENCING RELEASE EFFICIENCY OF BROWNBANDED (Supella longipalpa (F.)) COCKROACH PARASITIDS

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Reference: Pawson, B. M., H. Rajapakse & R. E. Gold. 1994. Factors influencing release efficiency of Brownbanded (Supella longipalpa (F.)) cockroach parasitoids. Proceedings of The National Conference on Urban Entomology. 1994.

ABSTRACT:

Several factors that influence the host finding ability of Anastatus tenuipes Bolivar y Peltain and Comperia merceti (Compere), two egg parasitoids of Brownbanded (Supella longipalpa (F.)) cockroaches, were evaluated in three Texas A&M University rooms. Highest parasitism levels of sentinel oothecae (48%) were obtained when both A. tenuipes and C. merceti were released. Increasing the number of females (100, 250 or 400 females) released increased sentinel parasitism levels for both species. At the highest density (400 females) A. tenuipes parasitized 52% of the sentinel oothecae, while C. merceti parasitized 15%. Increasing the number of release locations (1, 2 or 4 locations) within a room did not influence the parasitism levels obtained by A. tenuipes. However, C. merceti produced higher parasitism levels when released at four locations (33%) instead of one location (24%). Neither A. tenuipes nor C. merceti showed a preference for parasitizing live or freeze-killed oothecae. However, A. tenuipes produced more progeny on live oothecae (6.7) than on freeze-killed oothecae (0.6). Results indicate that A. tenuipes appears to be more effective than C. merceti, however releasing both A. tenuipes and C. merceti would be a good strategy to suppress Brownbanded cockroach infestations.

KEYWORDS: Supella longipalpa, Anastatus tenuipes, Comperia merceti, Parasitoid releases, sentinel oothecae

LABORATORY AND FIELD PERFORMANCE OF INSECTICIDE FORMULATIONS FOR GERMAN COCKROACHES, *Blattella germanica* (L.), CONTROL

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REFERENCE: Kaakeh, Walid, B. L. Reid & G. W. Bennett; 1994; Laboratory and field performance of insecticide formulations for German cockroaches, *Blattella germanica* (L.), control; Proceedings of The National Conference on Urban Entomology; 1994.

ABSTRACT: Field trials and laboratory bioassays to evaluate the performance of experimental and commercial insecticide formulations were conducted. Field trials determined the efficacy of bait products in controlling infestations of German cockroach in public housing units. No differences in population reductions among abamectin formulations (PT300-aerosol, PT320-gel, and PT310-dust) at any 1992 posttreatment interval were found. Cockroach suppression achieved by Avert formulations ranged from 75-96%; they were more effective than Maxforce. In 1993, PT-310 and Siege bait gave initial, significant reductions in trap catch through 1 wk posttreatment; thereafter, performance declined.

Contact activity and residual persistence of chlorpyrifos formulations on masonite and stainless steel panels were determined. Generally, neither FN-5354 nor NAF-53 provided greater contact activity or longer residual persistence than Dursban LO. All formulations had greater activity when applied to stainless steel than masonite substrates. Mortality produced by the three formulations increased with increasing exposure time, but all three formulations were less effective over time.

Diazinon and chlorpyrifos formulations were evaluated for their contact activity and residual persistence on masonite panels. In Test 1, KnoxOut (diazinon ME) was less persistent than Empire 20 (chlorpyrifos ME), and Empire 20 was less persistent than XGA-1152 (chlorpyrifos ME). In Test 2 Diacap (diazinon ME), KnoxOut, and Empire provided greater contact activity than the other products tested. In both tests, formulations applied to panels aged in the laboratory generally had greater residual persistence than treated panels aged in a greenhouse condition. All formulations became less effective over time.

The speed of action was determined for a 0.5% chlorpyrifos bait by probit analysis of cumulative mortality and a ratio test estimated the relative palatability of the bait for JWax-S and Muncie'86-R strains, as inferred from differential LT₅₀ and LT₉₅ between choice and no-choice bioassays. The bait effectively killed

both strains, with over 95% mortality. JWax-S strain was killed >3X faster than was the Muncie-R strain in both bioassays. Differential kill rates between choice and no-choice bioassays with both strains in relation to palatability at LT₅₀ and LT₉₅ were reported.

Contact activity and residual persistence of three cyano-pyrethroid formulations were determined. FCR-4545 WP (0.025% cyfluthrin), was superior to Tempo WP (0.05%) and Tempo EW (0.05%) on masonite panels. Tempo WP was more effective and had a longer residual lifetime than Tempo EW. Demon WP (0.1%) and deltamethrin SC (0.06%), when applied to masonite, produced mortality greater than Demon EC (0.1%) throughout the 56 d evaluation. At the 56 d aging, deltamethrin SC achieved higher mortality than Demon WP. Demon EC was less active on stainless steel than Demon WP or deltamethrin SC only at the shorter, 10 s exposure.

KEYWORDS: German Cockroaches, *Blattella germanica*, Laboratory Bioassay.

EVALUATION OF CULIGEL®-PESTICIDE FORMULATIONS FOR PROLONGED COCKROACH CONTROL

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REFERENCE: Levy, R., M.A. Nichols, T.W. Miller, Jr., and G. Clark; 1994; EVALUATION OF CULIGEL®-PESTICIDE FORMULATIONS FOR PROLONGED COCKROACH CONTROL; Proceedings of the National Conference on Urban Entomology; 1994

ABSTRACT: The efficacy of disquet and gel Culigel® superabsorbent polymer-based bait formulations of the organophosphate chlorpyrifos and/or the insect growth regulator pyriproxyfen was evaluated against German cockroaches (*Blattella germanica*) in a series of laboratory trials. Culigel® superabsorbent polymers were crosslinked potassium polyacrylate/polyacrylamide copolymer granules (100-350 micron) manufactured by Stockhausen, Inc. Bait ingredients consisted of formulations of imitation molasses, synthetic vegetable gums and dispersants. Results of bioassays against German cockroaches with single- and joint-action bait compositions of chlorpyrifos (Dursban® 4E) and/or pyriproxyfen (technical NyLar®) indicated that agglomerated disquet or hydrogel insecticide-bait formulations could provide long-term control of nymphs and/or adults. The data suggested that joint-action disquets could provide simultaneous control of mixed populations of nymphs and adults. The concentration of bait/inert ingredients in a disquet or gel formulation was observed to affect insecticide delivery profiles.

KEYWORDS: Culigel®, Superabsorbent Polymers, German Cockroaches, Controlled Release, Insecticides

STABILITY OF CYPERMETHRIN RESISTANCE IN A FIELD POPULATION OF GERMAN COCKROACHES

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REFERENCE: Robinson, Wm. H and J. Zhai. 1994. Stability of Cypermethrin resistance in a field population of German cockroaches. National Conference on Urban Entomology 1994.

ABSTRACT: Use of the pyrethroid insecticide cypermethrin for German cockroach control has led to the development of moderate to high level resistance, and control failure in some field populations. Field studies have demonstrated that resistance to cypermethrin can develop after limited application and little or no prior exposure of the population to pyrethrins or other pyrethroids. The German cockroach population (RHA) in apartments in Roanoke, VA (USA) developed a resistance ratio (RR, Susceptible/Resistant) LD50 180 within three years following exposure to one to two treatments per year. At this high level of resistance (RR LD50 180), applications of 0.2% (AI) cypermethrin provided approximately 20% reduction of German cockroach infestation.

A program to reduce and manage the cypermethrin in the RHA population was initiated in 1990. All applications of cypermethrin to the Roanoke apartments stopped in July 1990; an organophosphate was used for cockroach control. The level of cypermethrin resistance was periodically monitored by LD50 and KT50 evaluations on cockroaches live-trapped from representative apartments. The level of cypermethrin resistance declined slowly during the nearly 3.5 years of no exposure to cypermethrin. The RR LD50 dropped from a level of 180 in July 1990, to 123 in March 1991, to 66 in October 1991, to 41 in October 1992, and to 2.9 in October 1993. The LD50 evaluations were considered the most accurate measure of cypermethrin resistance. KT50 evaluations in 1990 indicated a RR KT50 2.9, and in 1993 the RR KT50 was 1.7. These data indicate that the complete removal of the selecting insecticide for a period of about three years was necessary to restore a level of cypermethrin susceptibility.

KEYWORDS: Resistance, German cockroach, cypermethrin

TOXICOLOGICAL, BIOCHEMICAL, AND ELECTROPHORETIC CHARACTERIZATIONS OF A RESISTANT STRAIN OF THE GERMAN COCKROACH

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REFERENCE: Scharf, M. E., J. Hemingway, B. L. Reid, & G. W. Bennett. 1994. Toxicological, biochemical, and electrophoretic characterizations of a resistant strain of the German cockroach. Proceedings of the National Conference on Urban Entomology. 1994.

ABSTRACT: In an attempt to determine the holistic resistance profile in a resistant strain of German cockroach (Muncie'86), we have conducted a combination of assays. In toxicological assays, the toxicity of 11 technical grade insecticides was assessed using the topical application method. In comparison to the susceptible (Johnson Wax) strain, the highest resistance ratios were found to the insecticides chlordane and bendiocarb. To examine the stability of resistance, chlorpyrifos and cypermethrin were tested repeatedly over 3 years. It was found that resistance levels did fluctuate significantly over this period, and an ANOVA showed the year effect to be the more variable (and the only significant; $\alpha = 0.05$) of the two effects examined. Assays utilizing piperonyl butoxide in addition to 4 insecticides showed a complete reduction in resistance only to bendiocarb. As a result, we have concluded that mechanisms in addition to cytochrome P450 monooxygenases are responsible for resistance in the Muncie'86 strain.

In biochemical assays it was confirmed that the Muncie'86 strain possessed cytochrome P450 monooxygenase levels which were elevated 2.4 fold over the susceptible strain. Esterases and glutathione-S- transferases were found to be active only in portions of Muncie'86 individuals. Esterases in the Muncie'86 strain were compared electrophoretically to the susceptible strain and were found not qualitatively different. There were, however, greater expressed amounts of esterase (i.e. darker bands) in the Muncie'86 strain at 3 electromorphs.

KEYWORDS: German cockroach, insecticide resistance, characterizations.

**ATTEMPTS AT THERMAL CONTROL OF RESISTANT GERMAN COCKROACH
POPULATIONS IN LARGE FOOD SERVICE FACILITIES**

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REFERENCE: Zeichner, Brian C.; 1994; Attempts at Thermal Control of Resistant German Cockroach Populations in Large Food Service Facilities; Proceedings of The National Conference on Urban Entomology; 1994

ABSTRACT: Intolerable German cockroach populations were experienced in several food service facilities. Sticky trap data indicated that pesticide applications were not reducing cockroach populations. Resistance ratios, determined using jar test time-mortality response, were high for chlorpyrifos, diazinon, propoxur, cypermethrin, and cyfluthrin, indicating the need for alternative control techniques. Four duct type, 400,000 BTU/Hour heaters were used to heat a 3,600 square foot facility with concrete block walls and a concrete floor. After 6.5 hours temperatures were 120⁰ to 140⁰ F throughout most of the facility. Numerous dead cockroaches were seen on and in equipment and on the floor. However, live cockroaches were found harboring in cool spots, particularly at the junction of the floor and wall. The trap index the night before thermal treatment was 46. Following application of heat the facility received a pesticide application similar to those previously used. The trap index 1 week post-treatment was 4.1, a 91% reduction from pre-treatment levels. At 3 month post-treatment it was 0.18, the lowest level reported in four years of record keeping. The large mass of concrete in these facilities makes it impractical to adequately heat all structural elements such as the floor. Future tests will investigate ways to prevent cockroaches from locating and using cool microhabitats.

KEYWORDS: German Cockroaches, Thermal Control

FINDING THE PARENT COLONY

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REFERENCE: Akre, R. D., L. D. Hansen and E. A. Myhre. 1994. Finding the parent colony. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Most recommendations for the control of carpenter ants in structures advise finding the parent colony. If the parent colony can be located and eliminated, the entire colony will eventually die. However, if only the satellite colony in a house is controlled, workers from the parent colony frequently re-infest the structure.

The general reaction from many pest control personnel is that finding the parent colony is nearly impossible, is very time consuming, and is not really necessary. After listening to these criticisms, we embarked on a research program to attempt to delineate procedures in locating parent colonies.

Of eleven structures inspected for carpenter ants in Spokane, parent colonies were positively located for five of the infestations within 15 minutes. Where parent colonies were not positively identified, 30-45 minutes was sufficient to identify the probable location of the parent colony. Ten parent colonies were located during a training session in Western Washington. No bait was used, but the locations of the parent colonies were determined in 15 to 90 minutes. In another series using bait, parent colonies were located in 10 min to 2 hours. Colonies of *Camponotus vicinus* required the longest time since this is a polygynous species that has multiple parent colonies.

Training sessions for PCO's during re-certification programs for licenses should probably include a "hands on" session for locating parent colonies.

KEYWORDS: *Camponotus*, carpenter ant, parent colony, location.

EFFICACY OF PYRIPROXYFEN FOR CONTROL OF DIFFERENT STAGES OF THE LONE STAR TICK, *Amblyomma americanum*

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REFERENCE: Donahue, W. A., P. D. Teel and R. W. Meola. 1994. Efficacy of pyriproxyfen for control of different stages of the lone star tick, *Amblyomma americanum*. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Newly engorged larvae and nymphs of the lone star tick, *Amblyomma americanum* L., were exposed to pyriproxyfen at dosages of 4, 8 and 16 $\mu\text{g}/\text{cm}^2$ and 7 days, 14 days, and continuous exposure periods at each concentration. Treatment of newly engorged larvae resulted in decreased molting, altered postmolt defecation and nymphal survival with results being dose and exposure dependent. Molting inhibition ranged from 34.6-81.6%. Successfully molted nymphs were lethargic, short-lived, and exhibited altered defecation patterns. In combination, these effects resulted in 82.6-100% control between 30 and 65 days postmolt. Subsequent adult longevity was most dramatically affected with 87.9-100% control achieved by 82-84 days postmolt. Fecal patterns and survivorship were dose and exposure dependent. Estimates of subsequent feeding success of adults treated as engorged nymphs show reduced capacities of attachment, engorgement and reproduction.

Engorged females and 1-3 day old eggs of the lone star tick, *A. americanum* L., were exposed to the 9 treatments described above. Treatment of newly engorged females did not affect the number of females ovipositing, but the number of eggs oviposited decreased as dosage and exposure time increased. Complete inhibition of egg hatch occurred at all treatment levels except that of the lowest dosage and exposure time where 99.9% inhibition was observed. Eggs from treated females were observed to 1) turn a dark amber color and implode, 2) retain normal shape and color without visible evidence of embryogenesis, or 3) have developed embryos which appeared unable to emerge. Treatment of 1-3 day old eggs was effective in reducing hatch and larval survivorship to 25 days post-emergence only with continuous exposure of dosages of 4, 8, and 16 $\mu\text{g}/\text{cm}^2$.

KEYWORDS: *Amblyomma americanum*, lone star tick, pyriproxyfen, IGR.

PEST SPECIES OF CARPENTER ANTS IN NORTH AMERICA

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REFERENCE: Hansen, L. D. and R. D. Akre. 1994. Pest species of carpenter ants in North America. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: North America has about 20 species of carpenter ants (*Camponotus*) in 4 subgenera that can be considered pest ants, either from a structural or a nuisance standpoint. However, since most personnel involved in the control of carpenter ants in the pest control industry are well-acquainted with the more common pest species of the East (*C. novaeboracensis*, *C. herculeanus*, *C. pennsylvanicus*) and of the West (*C. modoc*, *C. vicinus*), we chose to exclude these species to discuss several of the remaining 15 species that are less well-known. For example, *C. laevigatus* has been reported as a common pest in houses in the PNW, but it is not. However, the members of the subgenus *Myrmentoma* such as *C. caryae*, *C. decipiens*, *C. essigi*, and *C. nearcticus* are serious nuisance pests, and they are among the most difficult to control. Species in the subgenus *Tanaemyrmex* such as *C. castaneus* and *C. tortuganus* are sometimes pests, while a species in the subgenus *Mymothrix*, *C. abdominalis*, is a serious structural and nuisance pest in the South.

KEYWORDS: *Camponotus*, carpenter ant, pest.

PATTERNS OF FORAGING ACTIVITY OF THE SOUTHERN FIRE ANT, *Solenopsis xyloni* (MCCOOK), IN A COLONY OF AN ENDANGERED BIRD SPECIES

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REFERENCE: Hooper, L. M., M. K. Rust and D. A. Reiersen. 1994. Patterns of foraging activity of the southern fire ant, *Solenopsis xyloni* (McCook), in a colony of an endangered bird species. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Foraging activity of the southern fire ant, *Solenopsis xyloni* (McCook), was investigated by measuring the amount of bait particles removed from glass screw cap vials. Ant nest sites were located in a California least tern colony, an endangered bird species, on Coronado Island in San Diego, CA. Four mature ant colonies were monitored hourly by placing 2.0 g of untreated bait in glass vials 30 cm from each nest entrance. The amount of bait taken was determined by weighing the bait remaining in the vial. To avoid continuous recruitment of ants to the feeding site by trail pheromones, the new vial was placed 30 cm away from the nest entrance and 90 degrees from the position of the vial being replaced.

Solenopsis xyloni initiated foraging activity at 1600 hours when the study began in July 1993. By October 1993, foraging started at 1400 hours. This temporal shift when ant foraging was initiated is correlated with the time of sunset (approximately 4.25 hours before sunset). Foraging terminated by 0700 hours throughout the study. The intensity of ant foraging was found to increase significantly several hours after sunset with peak foraging between 2100 and 0300 hours. The level of ant activity was elevated in August and October with moderate foraging in July and September. No foraging occurred in November. Even though *S. xyloni* attacked the bird eggs and chicks in June and July, the maximum foraging patterns of the ant do not appear to coincide with the presence or nesting of least terns. These data have importance for determining the appropriate baiting strategies for control of the southern fire ant.

KEYWORDS: *Solenopsis xyloni*, southern fire ant, foraging, bait, endangered species.

**THE EFFECT OF HOST (*Felis catus*) ACTIVITY ON THE
DISTRIBUTION OF CAT FLEA LARVAE (*Ctenocephalides felis
felis*) INDOORS**

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REFERENCE: Kern, W. H. Jr., P. G. Koehler, R. J. Brenner and R. S. Patterson. 1994. The effect of host (*Felis catus*) activity on the distribution of cat flea larvae (*Ctenocephalides felis felis*) indoors. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: A house cat infested with cat fleas was placed in a 15.05 m² carpeted room. Its movements were recorded using a time lapse video cassette recorder. This tape record was used to produce a spatial and behavioral time budget. After four days of recording host behavior, the cat was removed and the flea larvae were extracted from the carpet. This was replicated five times.

Numbers of flea larvae in each 0.21 m² area of carpet were determined. This distribution of larvae was estimated and mapped using ordinary Kriging. Probability contours as larval density indicators were computed by giving the top 28% of larval counts a value of 1 and all other counts 0, and mapped using ordinal Kriging. This was repeated with the cat location data. The larval density indicator map was then subtracted from the cat spatial use indicator map to produce a continuity map.

Highest cat flea larval concentrations (42%) were found in the small areas where the host cat spent the majority of its time (79%). There were also numerous locations where larval concentrations were found, although the host cat spent no time in those locations. Activities such as jumping down from a high resting site cause flea eggs to be deposited in areas where the host spent very little time. The spatial distribution of cat flea larvae is a complex phenomenon that is influenced by host resting sites, host movement patterns and behavior, environmental factors, and larval movement patterns stimulated by those environmental conditions.

KEYWORDS: *Ctenocephalides felis*, cat flea, distribution, host, behavior

THE EFFECTS OF WASHING DOG AND CAT HAIR ON CAT FLEA, *Ctenocephalides felis* (Bouché), EGG PRODUCTION IN AN ARTIFICIAL HOST SYSTEM

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REFERENCE: Lawrence, W., G. Henderson and L. D. Foil. 1994. The effects of washing dog and cat hair on cat flea, *Ctenocephalides felis* (Bouché), egg production in an artificial host system. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: The artificial host system used in this study consists of a blood reservoir, a Parafilm® membrane, and a feeding chamber. The placement of animal hair in the feeding chamber gives adult fleas a substrate upon which to walk, mate, and lay eggs. The type of hair and its treatment may provide a potential source of variation in egg production. In our investigation, the possible effects of substrate type and three substrate treatments on cat flea egg production were explored.

Prior to placement into individual feeding chambers, samples of dog hair and cat hair were washed in either hexane, distilled water, or a 0.25% Woolite® solution for 30 minutes, removed, and air dried. The results show significantly lower egg production and survivorship in both distilled and Woolite® treatments when compared to unwashed controls. Hexane treatment was not significantly different from unwashed controls. Flea egg production on dog hair and cat hair was similar.

KEYWORDS: *Ctenocephalides felis*, cat flea, artificial rearing.

EFFECTS OF PYRIPROXYFEN ON CAT FLEAS

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REFERENCE: Meola, R. and S. Pullen. 1994. Effects of pyriproxyfen on cat fleas. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Adult cat fleas fed on the "artificial dog" synthetic membrane system began to die within 4 days when exposed to dog hair treated with pyriproxyfen. Mortality increased to over 90% within 6 days in fleas exposed to 12.5, 125 and 1250 ppm with approximately the same mortality for each dosage tested. Mortality rates at the lowest dosage, 1.25 ppm, were nearly identical to mortality of control fleas on acetone treated hair, which reached a maximum of 35% on day 10.

A similar dose response-induced mortality rate was demonstrated in another experiment when fleas were exposed to either pyriproxyfen or Juvenile Hormone III treated filter papers in glass vials. JH caused adult mortality only at a concentration of 110 $\mu\text{g}/\text{cm}^2$, 100 times the rate of pyriproxyfen used in this experiment. Therefore the lethal action of pyriproxyfen may be a pharmacological effect caused by the high JH equivalency of the pyriproxyfen molecule. As reported earlier, adult mortality is due to the rapid depletion of nutritional reserves stimulated by pyriproxyfen exposure.

We also investigated the effect of exposing flea eggs to pyriproxyfen residues. Previously, Marchiondo et al. (1990) reported that unembryonated cat flea eggs failed to hatch when they were exposed to fenoxycarb at 1.1 $\mu\text{g ai}/\text{cm}^2$ for 1 minute. Newly laid eggs (<4 hours) exposed at the same rate hatched. Ten minute exposure periods reduced egg hatch by 65% and killed approximately 50% of the first instars from the remaining eggs. Two hour exposure periods caused ovicidal effects and completely prevented egg hatch. Most of the eggs that were 24 and 48 hours old also failed to hatch when they were exposed to pyriproxyfen treated filter paper for intervals of 2 hours, although the sensitivity of eggs to shorter exposure periods decreased with the age of the egg.

KEYWORDS: *Ctenocephalides felis*, cat flea, pyriproxyfen, IGR.

EFFECTS OF NEST PROXIMITY AND ALTERNATIVE FOOD SOURCES ON BAIT DISTRIBUTION AMONG PHARAOH ANT, *Monomorium pharaonis* (L.), COLONIES

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P.O. Box 14565, Gainesville, Florida 32604

REFERENCE: Oi, D. H., K. M. Vail and D. F. Williams. 1994. Effects of nest proximity and alternative food sources on bait distribution among pharaoh ant, *Monomorium pharaonis* (L.), colonies. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Control of Pharaoh ant infestations in buildings that contain multiple colonies may be influenced by the proximity of toxic baits to nests. While Pharaoh ants may forage over 40 meters, the presence of alternative food sources may reduce foraging distances and thus hinder the finding and spread of toxic baits. Our objective was to document the influence of nest proximity and alternative food sources on the distribution of baits.

A 4.57 meter series of trays containing four Pharaoh ant colonies, with a dyed bait placed at one end and an undyed bait placed at the opposite end of the tray series, was used to model a multiple colony infestation. Colonies were located at distances of 15, 132, 310 and 427 cm from the dyed bait, and at reciprocal distances from the undyed bait. Within 24 hours, dye was observed in 98% of the Pharaoh ant workers from nests placed closest to the dyed bait. After 1 week, from closest to farthest from the dyed bait, 97, 88, 41, and 12% of the workers were dyed, respectively. After 2 weeks the pattern of dyed workers was 97, 95, 57, and 53% from nests closest to furthest from the dye, respectively.

The lower distribution of dye may be indicative of reduced toxicant distribution in colonies located farther from toxic baits and in closer proximity to an alternative food source. Assuming intercolony trophallaxis is an important means for food distribution among Pharaoh ant colonies, we hypothesize that the distribution of baits that contain faster acting metabolic inhibitors may not be spread to other colonies as efficiently as baits that contain slower acting active ingredients such as insect growth regulators.

KEYWORDS: *Monomorium pharaonis*, Pharaoh ant, bait, foraging.

DETERMINING EFFICACY OF FENOXYCARB AGAINST VARIOUS LIFE STAGES OF THE LONE STAR TICK, *Amblyomma americanum*, INFESTING DOGS

Kathleen G. Palma, Bill C. Clymer and Tony Janes

REFERENCE: Palma, K. G., B. C. Clymer and T. Janes. 1994. Determining efficacy of fenoxycarb against various life stages of the lone star tick, *Amblyomma americanum*, infesting dogs. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Eighteen individually-housed beagles of mixed sex and age, weighing 40 lbs. or less, were divided into test and control groups for this study. Fifteen pairs of adults, 50 nymphs, and approximately 200 larvae were placed on each animal. Each animal was sprayed until it was completely wet to the touch. Heads of the animals were sponged with material, taking care to avoid their eyes. Tick counts were made 14 days after infestation. Body counts were made without removing any ticks at days 2 and 14. Any ticks collected from the pans or cages were placed in vials and held in a humidity chamber for molting. Observations of the vials were made twice a week, monitoring tick activity.

Fenoxycarb did not appear to have any effect on larval or nymphal molts. There was no mortality associated with any life stage. However, adult females exhibiting normal oviposition had a decreased percentage of hatch within those eggs oviposited.

KEYWORDS: *Amblyomma americanum*, lone star tick, fenoxycarb, IGR.

THE POTENTIAL OF BIOLOGICAL CONTROL FOR ANT CONTROL

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REFERENCE: Patterson, R. S. and J. Briano. 1994. The potential of biological control for ant control. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: Two potential biological control organisms including a protozoan, *Thelohania solenopsis*, and a parasite, *Solenopsis daguerrei*, are being evaluated in the laboratory and the field to suppress fire ant populations. These organisms appear to have some detrimental effect on fire ants in the laboratory, but little is known of their true effect on field fire ant populations. In the laboratory, fire ant colonies infected with the protozoan *Thelohania solenopsis* quickly died. It is very effective in the field in reducing the size and number of fire ant colonies, but it is very slow-acting. More research needs to be done before this disease can be introduced into the United States, especially regarding its mode of spread. Still, this organism appears to have great promise as a potential biological control organism of fire ants. It has been reported in the literature that the parasite *Solenopsis daguerrei* will kill the queen and is very specific for fire ants. However, it is cyclic and does not seem to be very lethal to the fire ant colonies in Argentina, although it certainly has a draining effect on the host colony.

KEYWORDS: *Solenopsis*, fire ant, biological control, *Thelohania solenopsis*, *Solenopsis daguerrei*.

A NOVEL APPROACH TO PHARAOH ANT CONTROL - OUTDOOR SCATTER BAITS

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REFERENCE: Vail, K. M., D. H. Oi and D. F. Williams. 1994. A novel approach to pharaoh ant control - outdoor scatter baits. Proceedings of The National Conference on Urban Entomology, 1994.

ABSTRACT: A new concept of applying outdoor scatter baits for Pharaoh ant, *Monomorium pharaonis* (L.), control was studied. In a previous study, Pharaoh ant foragers were more abundant outdoors than indoors. Thus, the use of an outdoor scatter bait would exploit the workers' tendency to forage outdoors. Our objective was to evaluate a scatter bait containing hydramethylnon for controlling the Pharaoh ant both indoors and outdoors. This bait was applied to the ground surrounding the exterior perimeter of a house and other outdoor locations where ants were actively foraging. A survey had determined the houses had active outdoor and indoor populations of Pharaoh ants. Evaluations of the treatments were made by placing index cards containing about 1 cc of peanut butter throughout each house. Locations of the index cards and the number of ants per card were recorded for the pretreatment data. Treatments were evaluated at 1, 4, and 8 weeks after bait application by placing the index cards containing peanut butter in the same locations as the pretreatment readings. The reductions in proportion of median ant numbers and in proportion of cards containing ants were compared using nonparametric statistics. Most ants were found outdoors, so these data best represent the effects of the scatter bait treatment. Outdoors, the proportion of the index cards containing ants was significantly reduced in the scatter bait treatment for all posttreatment evaluation dates. The proportion of reduction of the median number of ants was significantly greater in the scatter bait treatment than in the control up to four weeks after bait application. Indoors, the proportion reduction of cards containing ants and of median ant numbers were significant for only one week. The lack of significant reduction in these variables after one week may be due to the decrease in the number of ants observed indoors in the control houses.

KEYWORDS: *Monomorium pharaonis*, Pharaoh ant, control, bait.

NATIONAL CONFERENCE ON URBAN ENTOMOLOGY

February 20-22, 1994

Marriott Marquis
Atlanta, Georgia

Sunday, February 20th

10:00 am - 1:00 pm **REGISTRATION** - Marquis Registration Booth

Marquis Salon I
Moderator: Gary Bennett

1:00 - 1:30 pm **INTRODUCTION AND WELCOME**

Roger Gold, Texas A&M University
WELCOME FROM THE GEORGIA PEST CONTROL ASSN.
Ralph Sanford, President

1:30 - 2:30 pm **Arnold Mallis Memorial Lecture**

URBAN PEST CONTROL - A STRONG FOUNDATION
John Osmun, Purdue University

2:30 - 3:45 pm **SAMPLING GERMAN COCKROACH FIELD POPULATIONS**

Byron Reid, Purdue University
Arthur Appel, Auburn University

4:00 - 6:00 pm **RECEPTION** - Skyline North, 10th Floor

6:00 pm **DINNER ON YOUR OWN**

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Monday, February 21st

Marquis Salon I
Moderator: Bill Robinson

8:00 - 9:00 am **CURRENT FINDINGS IN FLEA RESEARCH**
Mike Dryden, Kansas State University

9:00 - 10:00 am **TERMITE BAITS IN THEORY AND PRACTICE**
Jim Tranterello, Boston University
Barbara Thorne, University of Maryland

10:00 - 10:30 am **COFFEE BREAK** - Marquis Foyer

10:30 - 11:30 am **NEW TECHNOLOGIES IN DRYWOOD TERMITE MANAGEMENT**
Rudy Scheffran, University of Florida

11:30 am - 1:30 pm **POSTER SESSIONS** - Marquis Foyer
George Rambo, Organizer

12:00 - 1:30 pm **GROUP LUNCHEON** - Marquis Salon II

1:30 - 2:50 pm **CONCURRENT PAPER SESSIONS**
Mike Dryden, Organizer

TERMITE Marquis Salon I
Moderator: Jack Ryder

COCKROACHES Bonn Room
Moderator: Pat Zungoli

FLEAS, ANTS, TICKS & OTHER URBAN PESTS Sidney Room
Moderator: Nancy Hinkle

2:50 - 3:30 pm **COFFEE BREAK** - Marquis Foyer

3:30 - 5:00 pm **CONCURRENT PAPER SESSIONS**
Mike Dryden, Organizer

TERMITE Marquis Salon I
Moderator: Barbara Thorne

COCKROACHES Bonn Room
Moderator: Eric Benson

FLEAS, ANTS, TICKS & OTHER URBAN PESTS Sidney Room
Moderator: John Klotz

6:00 pm **RECEPTION** - Marquis Foyer

7:00 pm **BANQUET** - Marquis Salon II
Phil Hamman, Master of Ceremonies
Gary Bennett, Awards Presentation

Tuesday, February 22nd

Marquis Salon I
Morning Moderator: Roger Gold

8:00 - 9:00 am **MAJOR FLEA & TICK-BORNE DISEASES IN THE US - CURRENT STATUS**
David Dennis, CDC

9:00 - 10:00 am **VERTEBRATES IN THE URBAN ENVIRONMENT - RESEARCH FINDINGS AND RESOURCES AVAILABLE**
Bobby Corrigan, Purdue University

10:00 - 10:30 am **COFFEE BREAK** - Marquis Foyer

10:30 - 11:30 am **PHARAOH ANT BIOLOGY AND CONTROL**
David Williams, USDA Gainesville

11:30 am - 1:00 pm **LUNCH ON YOUR OWN**

Marquis Salon I
Moderator: Don Relerson

1:00 - 2:00 pm **IMPLEMENTING COCKROACH IPM PROGRAMS**
Mike Rust, University of California-Riverside

2:00 - 2:30 pm **COFFEE BREAK** - Marquis Foyer

2:30 - 3:30 pm **WHERE URBAN ENTOMOLOGY STANDS TODAY: WHAT ABOUT THE FUTURE?**
Coby Schal, North Carolina State University

3:30 - 4:00 pm **MEETING SUMMARY, CONCLUSIONS AND FUTURE DIRECTIONS**
Roger Gold, Texas A & M University

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