The Science of Baiting Urban Pests

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Presentation Abstracts

Current Issues and Future Directions in German Cockroach Baiting-Part I. Donald A Reierson. Department of Entomology, University of California, Riverside, CA 92521

There is an increasing use of baits by PCOs as levels of effectiveness delivered by baits improve and as customers demand safer and more effective treatments. In response to client concerns about the impact of insecticides, many PCOs have turned to baits and other perceived low-impact strategies to help control pests such as cockroaches indoors. As more bait products become available to professionals it is important to know about the strengths and weaknesses of baiting, and how best to use bait in cockroach control programs.

That German cockroaches are a widespread problem is no surprise. We found that two-thirds of 100 randomly surveyed restaurants in Los Angeles were positive for German cockroaches in spite of being under professional service. Few PCOs servicing these accounts used bait, and most who did were not using bait properly.

In spite of many baits available as solids and gels, containerized and loose, and with various active ingredients including boric acid, chlorpyrifos, fipronil, hydramethylnon, NMD, propoxur, sulfluramid, and others in our experiments cockroaches are seldom eliminated with bait alone. As we see it, major current issues concerning bait relate to the dichotomy between the potential effectiveness of bait in the laboratory and the less than perfect control usually encountered in the field.

Bait test results vary according to how the test is conducted. An important issue facing researchers is how best to test with positive predictive value and how to interpret bait data critically and relate it to real-world situations. Tests with cockroaches in small arenas show a indirect relationship between bait efficacy and presence of competitive food or water. We have scaled-up such tests to include 12-chambered olfactometers in which we also demonstrated a direct relationship between bait efficacy and number of bait placements. Ultimate kill with improved as the number of chambers baited increased. These relationships were confirmed in the field with virtually every bait we have tested.

Differential foraging activity and susceptibility of males, females, and nymphal cockroaches may affect bait success. It is not clear to what extent the relative inactivity of gravid females affects bait effectiveness. Our research indicates none of the stages are attracted to food over distance, but some degree of deprivation appears to trigger intense foraging that increases the probability of the cockroaches encountering bait. Stylized edge-effect foraging appears to be important in terms of bait placement. Relationships between bait placement and sanitation and bait efficacy need to be studied.

The role of secondary kill via coprophagy and important issues such as the effect of insecticide resistance and learning need to be fully explored as they relate to cockroach baiting. Our work suggests a limited role for coprophagy, but an understated role of resistance. Although resistance may be overshadowed by overdoses consumed by cockroaches when they eat bait, resistant cockroaches consuming a sublethal amount of bait may avoid future bait encounters if competitive food is available.

Current Issues and Future Directions in Cockroach Baiting-Part II. Arthur G. Appel. Department of Entomology, Auburn University, 301 Funchess Hall, Auburn, AL 36849

Insecticidal baits are generally composed of a toxicant, a food base with preservatives, and water (in gel and paste formulations). In addition, many bait products are enclosed in child-resistant bait stations. Each component of a bait formulation as well as the exposure station is critical for maximum performance. For example, many toxicants are repellent and cockroaches will not consume sufficient bait. Water-laden gel and paste formulations dry out over time resulting a higher concentration of toxicant and a much different texture than when the formulation was first applied.

The results of laboratory bioassays of baits can be greatly affected by how the bioassay is set up. Toxicity is greatly affected by the amount of available dark harborage. Toxicity is affected by food and water deprivation; 72 hours of deprivation of either food or water results in enhanced toxicity. Different stages of the German cockroach, *Blattella germanica* (L.) are differentially sensitive to the same bait, therefore field performance estimates should be based on toxicity data from more than just one stage (typically adult males).

Performance of baits in real apartments can be affected by the number of bait stations or placements, proper positioning of the bait, and the presence of additional chemicals in the environment. Some of the reasons baits sometimes fail include complete consumption of the bait, repositioned bait stations, coating of a station or deposit with a repellent material, or that the bait works too slow or too fast. Behavioral and physiological resistant to the toxicant or other bait component, monitoring problems, and intra- and interapartment movement also affect bait performance.

Current issues for cockroach bait development and use include the need to increase performance of current products through better application methods and appropriate formulations, and integration of bait technology with conventional insecticides, growth regulators, and structural modifications. Future directions for research should focus on developing a better understanding of the ecology of the kitchen environment and development and validation of IPM systems for cockroach control. Given the medical importance of cockroaches, we should always keep a firm understanding of our ultimate IPM goal.

Current Issues and Future Directions in Ant Baiting-Part I. John H. Klotz. Department of Entomology, University of California, Riverside, CA 92521

Three areas of research are described that have great potential for bait development: (1) enhancement of baits using pheromones, (2) determination of food preferences, and (3) new bait formulations and delivery systems.

Owing to the primary importance of chemical communication in ants, bait formulations enhanced with pheromones or volatile food components is a promising area of research which has not been adequately addressed yet by industry or academia. Dr. Les Greenberg has demonstrated with Argentine ants the enhancement of baits with their trail pheromone, cis-9-hexadecenal. The importance of olfaction in carpenter ants can be inferred by the large and complex antennal lobes of their brain. New bait technology should be exploiting this sensory system and the behaviors associated with it.

Food preference studies rank high on industry's priorities for research in bait development. There has been considerable research on sugar preferences of various pest ants, but less work on other dietary components. To formulate good combination baits, more information is needed on dietary requirements and preferences for proteins and fats.

To optimize collection, transport and sharing of baits we must address formulations and delivery systems. Granulars are becoming more popular but their application may not be exploiting the natural behavior of ants. Liquids may have potential because they capitalize not only on the natural behavior of ants feeding on honeydew and nectar but also on the specialization of the digestive system of some ants to handle these liquid foods.

Current Issues and Future Directions in Ant Baiting-Part II. David H. Oi. Department of Entomology, Auburn University, 301 Funchess Hall, Auburn, AL 36849

Traditional development of an ant bait involves identifying target species, determining food preferences, and developing an acceptable food/toxicant matrix. Toxicants have been selected based on the criteria of Stringer et al. (1964) where the toxicant must a) exhibit a delayed action over a 10 to 100+ fold dosage range; b) be transferred between ants and kill the recipients of the toxicant; and c) not be repellent when combined with the food matrix. Once these criteria are met, further refinements in the bait matrix and delivery system must be made to maintain toxicant efficacy and bait acceptability to the targeted ant(s). The above criteria have been used to develop baits that utilize metabolic inhibiting active ingredients, such as hydramethylnon and sulfluramid. Active ingredients with other modes of action, such as insect growth regulators, do not exhibit the 1 to 3 day delay in mortality but cause a more gradual increase in mortality.

There are many factors that influence the efficacy of ant baits. Bait consumption is driven by the nutritional needs of the ant colony, and consideration of how ants meet these needs may help explain some of the variation in efficacy. Nutrient management within an ant colony is influenced by the presence of multiple worker castes, for example brood tenders and foragers; by larvae that rely on workers for food procurement; and by the multi-year longevity of queens and colonies. These characteristics of an ant colony are then further coordinated with seasonal colony cycles, such as the production of reproductives and mating flights, and environmental cycles that affect food availability and colony activity [e.g. cold weather may slow activity] (Wheeler 1995).

Red imported fire ants illustrate this coordination of the flow of nutrients through a colony. Worker populations decline from January to midyear, which coincides with the production of the reproductive caste and their major mating flights in early summer. Worker fat content declines gradually through winter, with the lowest fat levels occurring in June after the spring production of reproductives. Hence worker fat may be expended for overwintering and the production of reproductives, while from July through the fall worker fat content increases as lipid resources become available and are accumulated (Tschinkel 1993).

Another factor of nutrient management and flow within a colony is starvation. Starved colonies presented with food exhibit more foraging, greater consumption, and faster food distribution within the colony. The nutritional value of food also affects its distribution within a colony. Proteins used for eggs and growth are often shunted to queens and larvae. Carbohydrates, which provide energy, are directed more toward active workers, while lipids, which represent a reserve energy resource, may be preferentially fed to workers and larvae. The form of the food also influences its colony distribution. Liquids can be ingested by workers directly, while solid foods must be liquefied first and this task falls to fourth instar larvae in fire ant colonies. Thus foraging workers have the initial opportunity to ingest liquids, while larvae have initial access to solids.

While the nutritional status and form of a bait's food component can affect its distribution rate, properties of the bait toxicant also influences its colony distribution.

Metabolic inhibitors which act within a few days are not distributed as thoroughly as slower acting IGRs among ant species that have multiple queens and colonies. Ants may also reject baits after partial distribution and ingestion among colony members. Thus the delay in toxicity is critical in allowing for toxicant distribution throughout a colony before rejection occurs. A propensity for some ant species to store food also may be a factor in bait efficacy. IGRs may require a prolonged exposure within a colony, thus these species may be more susceptible to these types of baits.

Assuming that a bait will be consumed, an important factor of efficacy is the availability of the bait to foraging ants. Temperature, precipitation, and circadian rhythms all affect foraging times. Applying baits when and where ants are foraging is crucial if the palatability and/or efficacy of the bait degrades rapidly. In addition, foraging times may shift due to seasonal weather patterns, colony hunger, competition with other ants or organisms, and predation. Finally, the presence of alternative food sources that compete with baits is a major factor of variations in bait efficacy.

Development of a single ant bait that is effective for all pest ants is improbable. Thus potential research areas should focus on the improvement of baiting techniques (e.g. delivery systems, placement), field evaluations, and bioassays with respect to the biology of individual pest ant species. In addition, since ant baits now target reproducing queens, developing baseline data to detect the possible development of resistance should be considered. Ant baiting is complex given the tremendous behavioral diversity of ants and an end user that often has limited time and experience to solve an ant problem. Our challenge is to understand the critical factors that influence ant baiting and to provide the technology and education to overcome the complexity.

Stringer et. al. 1964. Imported fire ant bait studies: an evaluation of toxicants. J. Econ. Entomol. 57: 941-945.

Tschinkel, W. 1993. Sociometry and sociogenesis of colonies of the fire ant, *Solenopsis invicta*, during one annual cycle. Ecological Monographs 63: 425-457.

Wheeler, D. E., 1994. Nourishment in ants: patterns in individuals and societies. *In* [J. H. Hunt & C. A. Nalepa eds.] Nourishment and Evolution in Insect Societies. Westview Press/Oxford & IBH Publ. pp. 245-278.

Poster Abstracts

1. Implications of mouth part morphology to ingestion of food materials in *Camponotus modoc*. Laurel D. Hansen. Biology Department, MS 3080, Spokane Falls Community College, 3410 W. Fort Wright Drive, Spokane, WA 99224-5288.

Food materials are filtered at several points before and during ingestion into the alimentary canal. First, as food passes over the glossa into the infrabuccal pocket, the ridges on the glossa close against the buccal plate, which forms the dorsal side of the pocket. Secondly, as food is pumped out of the pocket into the pharynx, the buccal plate meets with the posterior surface of the epipharynx which contains ridges and hairs also projecting toward the infrabuccal pocket.

Glands in the head or associated with the anterior part of the alimentary canal include (1) the labial or salivary glands located in the dorsolateral regions of the thorax and empty through ducts which open between the hypopharynx and the labium, (2) the mandibular glands and reservoir located just above the base of each mandible, (3) propharyngeal glands located on the anterior surface of the pharynx and open into the pharynx, (4) maxillary glands which lie on either side of the pharynx near the infrabuccal chamber, and (5) the postpharyngeal glands which lie on the dorsal surface of the pharynx. The possible interactions of these gland secretions with the pellet of food contained in the infrabuccal pocket have not been investigated.

Why is food stored in the infrabuccal pocket for long periods of time? How much digestion occurs in the infrabuccal pocket? Are the bacteria found in the infrabuccal pocket mutually symbiotic? Answers to these questions related to ingestion and digestion may provide some answers to bait development in carpenter ant control.

2. Preference for commercial baits by field colonies of *Camponotus pennsylvanicus*. Jason M. Tripp, Daniel R. Suiter and Gary W. Bennett. Department of Entomology, Purdue University, 1158 Entomology Hall, West Lafayette, IN 47907.

We determined the palatability of several baits to the black carpenter ant, *Camponotus pennsylvanicus* (DeGeer). Rate of removal for 3 granular ant baits (Niban, Baygon, and Maxforce) was determined in the spring and fall. Regardless of season, Maxforce was preferred over both Baygon and Niban; Maxforce was more preferred in the spring than in the fall. During spring, the rate of removal of Maxforce granules was correlated negatively with time, suggesting a decline in interest. Seasonal differences in Maxforce preference may be due to a change in food preference or a negative reinforcement resulting from previous exposure.

3. New method for estimating population reduction following treatment of carpenter ant field colonies. Daniel R. Suiter[1] and John R. Moffett[2]. [1]Department of Entomology, Purdue University, 1158 Entomology Hall, West Lafayette, IN 47907, [2]Department of Computer Science, Purdue University, 1390 Math Hall, West Lafayette, IN 47907.

An electronic method for estimating field populations of carpenter ants, *Camponotus pennsylvanicus* (DeGeer), is described for use in evaluation of insecticide treatments (esp. baits) against this pest. Capacitive proximity sensors connected to compact dataloggers were placed 1 cm above permanent carpenter ant foraging trails for 1 h during the scotophase, and the number of ants passing under each sensor recorded. Population estimates from two sensors simultaneously detecting ants from a single colony typically differed by 22%.

4. When baits don't work. Jay Bruesch. Plunkett's Pest Control, Inc., 2828 11th Avenue South, Minneapolis, MN 55407.

The more sophisticated and varied the choice of insecticide bait produces becomes, the more frequent become the instances where a technician complains that a new bait, which hailed as a miracle month before, suddenly doesn't work anymore--or doesn't seem to work! Cockroach and ant bait products are emphatically accepted because of early successes, and then the honeymoon in over. Why?

Sometimes, but not always, it is applicator error that causes a bait to fail after initially succeeding. Sometimes there is resistance--behavioral or otherwise-- that challenges the pesticide manufacturing industry to come up with better solutions. And sometimes, to a limited extent, it is our industry's mindset that is causing the problem.

There are ÒMagic BulletÓ expectations according to which pest control people currently evaluate the decide wither to use new products. We wait for new products to come down from on high, and try them. Maybe they work very well. Soon they don't seem to work as well anymore, and we try the next thing to come along, without asking why the previous product failed. This cycle of failure must be replaced by a new paradigm, one which starts with the obvious: Baits are designed to be eaten. Pest control professionals must concentrate on the eating behavior of their target pests when selecting control materials. A thorough knowledge of the identification, biology, and behavior of the target pests will enable professionals to use existing and new baits in imaginative ways, and to outsmart pests at their own game: eating.

Reasons for bait failure include: (1) too few bait placements, (2) baits used in hot & dry environment, and did not supply a needed moisture requirement, (3) bait spoiled in a high humidity environment, (4) bait was contaminated by a subsequent application of insecticide, (5) baits were placed in wrong fashion (e.g., on top of ant mound when should be scattered around mound), (6) the technician used cologne, aftershave or strongly-scented soaps and then handled baits, (7) not enough bait used, (8) re-infestation, (9) wrong bait used for species involved, (10) high hopes based on anecdotal reports of a successful bait did not come true, (11) temporary change in the dietary preference of the pest species, (12) pests were misidentified, (13) the bait was allowed to absorb pesticide odors in the truck, (14) the technician smoked and then handled baits, and (15) the baiting program was sabotaged by the client.

5. Antswers needed: Issues facing urban pest control professionals in ant control.
Stoy A. Hedges. Terminix International, 860 Ridge Lake Blvd., Memphis, TN 38120.

Most of the research performed in the arena of urban structural pest management involves cockroaches and termites. Outside of the imported fire ant, *Solenopsis invicta* Buren, ants receive little attention save for a small number of dedicated urban myrmecologists. Yet, ask any pest control company and most will tell you that their most difficult pest to control in buildings are one or more species of ants.

At Terminix, the largest percentage of calls from residential customers result from ant invasions. Cockroaches rank a distant third or fourth in residences. Outside of food service and apartments, where ants usually rank second to the German cockroach in importance, and warehouses where rodent rank first, ants are also the most important pest of commercial structures.

Ants are the most successful creatures in the natural environment. Their complex societies are still poorly understood, yet researchers and, especially, insecticide manufacturers, treat most ant species as similar in biology and habits. Although several new baits have recently been introduced to the market, they still target the same species controlled by current commercial baits. The most difficult pest ants still resist efforts at a baiting strategy.

More research must be targeted as these difficult species. Carpenter ants and Argentine ants receive the most research attention and rightly so given their importance. Still, other species can be even more difficult to control than these two ants; the prime culprit being the crazy ant, *Paratrechina longicornis* (Latreille). The crazy ant is widespread through the southeast U.S. and occurs in a number of northern metropolitan areas. Crazy ants are excellent hitch hikers in tropical plants and recyclable materials, and once introduced, they do very well inside commercial buildings (e.g., hospitals and hotels).

Florida, in particular, faces a huge structural ant dilemma. Urban pest service professionals may regularly encounter 12 or more species during the course of their duties. Crazy ants drive both professionals and consumers crazy, and ghost ants are also a huge issue in Florida. In south Florida, the white footed ant, *Technomyrmex albipes* (fr. Smith), has proven almost impossible to control in a single structure. *Paratrechina bourbonica* (Forel) is somewhere between the crazy ant and the white footed ant in a professional's ability to solve (eliminate) a customer's ant infestation. How long before commerce spreads any of these species to your region of the country?

6. The significance of coprophagy. Robert J. Kopanic, Jr. and Coby Schal. Department of Entomology, North Carolina State University, Box 7613, Raleigh, NC 27695.

The significance of coprophagy to first and second instar German cockroaches was examined by forced exposure to conspecific fecal material as the only food resource. First instars exposed to adult fecal material survived 8 days longer on average than insects that were starved. However, survivorship of second instars and adults was unaffected by feces. Feces from adult males and females produced similar results and the age of feces (2 days, 1 week, 2 weeks) had no significant effect on longevity. Feces produced from individuals that fed on different defined nutrient diets (5, 25 or 55% protein) did affect first instar longevity. Low and medium protein levels produced similar results but exposure to feces from 55% protein diet resulted in increased longevity.

II. The contribution of horizontal transfer to overall mortality.

A novel experimental design that selectively excluded feeding of adults or nymphs on an insecticide bait was used to distinguish mortality caused by ingestion of bait from mortality caused by horizontal transfer of insecticide by foraging to nonforaging cockroaches. In large cage laboratory assays and in apartments, exposure of German cockroaches to an insecticide bait containing hydramethylnon resulted in high mortality in adult females and first instars. However, exclusion of adult females from feeding on the bait resulted in a significant decline in mortality among nymphs, suggesting that neonate mortality was caused primarily by adult-mediated horizontal toxicant transfer through feces. Conversely, mortality among second instars was high and significantly less dependent on adult foraging suggesting a shift to active foraging during the second stadium. Differences in foraging between first and second instars were documented by video recording visits to baits throughout a 48 hour period. Our results clearly demonstrate that second instars forage significantly more than first instars.

III. Coprophagy is the mechanism of horizontal transfer

Silverman et al. (1991) first proposed that German cockroaches redistribute ingested insecticides within aggregations and concluded from laboratory translocation assays that coprophagy plays a major role in this process. Although this mechanism has been demonstrated in small arena laboratory assays it remains unknown whether various life stages are equally susceptible to this approach and what role, if any, coprophagy serves in suppressing field populations of cockroaches. Survivorship and exclusion assays strongly suggest that coprophagy is the mechanism of horizontal toxicant transfer. To test this hypothesis we incorporated a tracking dye (Solvent Green 3) into ground rat chow and pulse fed adult "donor" insects. These insects were housed with first or second instars in large cages in the laboratory and in apartments. Any dye recovered from internal homogenates of nymphs following an external rinse would indicate coprophagy. The effect of proximity of food and on the level of coprophagy was also tested by varying the distance between 5 cm and 125 cm and by removing food from the assays. As food was moved farther from the shelter the amount of dye recovered increased in both first and second instars suggesting that coprophagy becomes more important when food is not readily available. When food is removed from the assay, dye recovery increases dramatically suggesting that coprophagy is critical when food is absent or scarce.

7. Bait development for urban pest ants. John H. Klotz and Les Greenberg. Department of Entomology, University of California, Riverside, CA 92521.

Baits are rapidly becoming the preferred technique for controlling household ant pests. In recognition of this increased popularity of baits we present our methods for developing and evaluating them to serve as models and as a basis for comparison with procedures used by other laboratories. Our focus is on bait development for carpenter ants, Pharaoh ants, fire ants and Argentine ants. We outline procedures for determining food preference, oral toxicity, and pheromone enhancement. We give examples of the types of statistics used to analyze results from these tests. For more information refer to the 1997 article by Klotz, Reid and Williams entitled ÒLaboratory and Field Techniques for Development and Evaluation of a Bait for Urban Ant Pests,Ó in Recent Research Developments in Entomology, Volume 1, pages 83-92.

8. Toxicity of four insecticides to Argentine ants. Linda M. Hooper, Michael K. Rust and Donald A. Reierson. Department of Entomology, University of California, Riverside CA 92521.

The Argentine ant, *Linepithema humile* is an exotic pest ant species that is widely established in California and throughout the southern United States. Historically, barrier sprays have been used with marginal success by urban pest control applicators to suppress Argentine ants with nearly 59% of properties being retreated because customers complained of ants persisting after treatment. Recently, baiting has been implemented which allows for the reduction in active ingredients applied around structures. Unfortunately, currently available ant baits only suppress Argentine ant populations but do not provide eradication. We conducted comprehensive toxicological studies on four pesticides against Argentine ants. Abamectin, boric acid, fipronil, and hydramethylnon were examined during 24-hr and continuous exposures of ants to each toxicant in a liquid matrix. Total mortality was achieved with Argentine ant workers exposed for 24 hours to very low concentrations of fipronil (1 x 10^{-5} %) and hydramethylnon (0.1%). Fipronil (1 x 10^{-5} %) was the only compound that resulted in 100% mortality to Argentine ant queens when exposed for 24 hours. Continuous exposure to boric acid (0.5%), fipronil (1 x 10^{-6}%), and hydramethylnon (0.025%) provided 100% mortality of workers. Argentine ant queens continuously exposed to fipronil (1 x 10^{-5} %) and boric acid (0.5%) all died within two weeks.

9. Effects of a JH analog on foraging behavior in carpenter ants. Samuel N. Beshers and Gene E. Robinson. Department of Entomology, University of Illinois, 505 South Goodwin Avenue, Urbana, IL 61801.

Experiments were done with carpenter ants, *Camponotus pennsylvanicus*, to test whether juvenile hormone (JH) is involved in regulating the transition from nest work to foraging in carpenter ants, as has been shown in honey bees, and whether treatment of a colony with a JH analog can increase the foraging intensity of a colony.

In the first experiment, workers from large stock colonies were treated with either hydroprene (100 ug/worker, in 1 ul acetone) or acetone alone, and combined into experimental colonies of 200 treated and 200 control workers. In two replicates, more treated workers began foraging, and treated workers began foraging sooner, than control workers. In the second experiment, two colonies were fed on sugar water that contained either 1 ug/worker of hydroprene with acetone and an emulsifier, or the acetone and emulsifier alone. In the treated colony, more workers began foraging, and the level of foraging activity was higher, than for the control colony.

These results suggest that JH analogs could be used in a bait to increase foraging and enhance bait efficacy.

10. Nutritional ecology of German cockroaches in the field. Stephen A. Kells[1], James T. Vogt[2], Arthur G. Appel[2] and Gary W. Bennett[1]. [1]Department of Entomology, Purdue University, 1158 Entomology Hall, West Lafayette, IN 47907, [2]Department of Entomology, Auburn University, 301 Funchess Hall, Auburn, AL 36849

Nutritional ecology plays a critical role in the use of baits to control German cockroach infestations. However, the effects of nutrition on the biology of cockroaches have largely been evaluated in laboratory situations with minimal studies reflecting *in situ* (in the field). Previous studies reveal evidence that *in situ* German cockroaches are nutritionally stressed, but defining this nutritional status would provide valuable information about diet selection and foraging behavior. The first study estimated the availability of protein, fat and carbohydrates for German cockroaches, *in situ*, by comparing the physiological indicators of cockroaches from the field versus those provided meridic (defined) diets. The resulting diet available to *in* situ cockroaches consists of 9% protein and equivalent amounts of fats and carbohydrates. Compared to rodent chow, the *in situ* diet has lower protein and considerably higher fat content. With the nutritional status defined, differences were evaluated in diet selection and foraging behavior of German cockroaches provided a diet reflecting *in situ* or rodent chow. Cockroaches fed the *in situ* diet favor proteins over fat and carbohydrates; whereas cockroaches fed rodent chow also consume protein, but tend to favor fats and carbohydrates depending on concentration. Foraging behavior is also affected by previous diet. Cockroaches forage for nutrients that are lacking (or limiting) in the diet, with the effect of distance serving a secondary role. Once a suitable food source is found at a particular station consumption at successive stations decline with distance.

This research has important ramifications for studying and controlling the German cockroach infestations. First, as the previous diet will affect the diet selection and foraging behavior, future nutritional studies using German cockroaches should include a diet that reflects *in situ*. Second, the nutrient content is a critical consideration when formulating insecticidal baits, because the German cockroach will select a diet to ensure complete nutrition. If baits lack components that cockroaches are selecting for (i.e. protein and carbohydrate), there may be increased interference from alternative food sources, resulting in less efficacy. Finally, placement of baits close to suspected harborage areas will ensure effective control, particularly if alternative foods are available.

Research Priority List: Ants

Discussions on research priorities for pest ants were led by John Klotz, Stoy Hedges, David Oi, and Les Greenberg. The difficulty in arriving at a list of research priorities for pests ants was due to the species diversity with which this discussion group had to deal. The research list that follows is a compilation of ideas deemed important to the study of all pest ant species. The following list of priorities is in descending order of importance (i.e., the most important topic is listed first).

(1) Ant species switch **food preference** from one season to the next, based primarily on colony nutritional demands. Although this phenomenon is known for several species, it was discussed that a nationwide **survey of urban ant fauna** and their food preferences through the year might help shed light on the use of baits in specific regions of the U.S. It was suggested that protocols be developed whereby PCOs (or other relevant cooperators) from around the U.S. could help collect ant samples from around and inside structures on a periodic basis throughout the year. Uniform baits containing predominantly carbohydrate, or fat, or protein would be standardized, and response to foods standardized by placement in all U.S. regions during all seasons at the same time of day.

- Standardized diet
- Use of PCOs
- Nationwide studies
- Optimize bait schedules (time of day must be cool)
- When to start treatments (month?)
- Organize protocols

(2) Bait delivery systems were an important priority. Particularly, research into the response of ants to the physical characteristics (see below) of bait stations was considered important.

- Types of systems
  - Stations (physical characteristics)
    - texture
    - size & shape of entrance
    - size & shape of feeding arena
    - color
    - environmental interaction

(3) The issues of **bait avoidance and bait rejection**, and how these phenomena might be minimized or eliminated were important topics. In particular, research into learned avoidance (i.e., from exposure to sublethal quantities of bait), the importance of the bait matrix and the active ingredient in determining acceptance (i.e., are either or both a feeding deterrent?), the effect of the age of the bait on acceptance, and as previously mentioned the influence of seasonal changes in food preferences among the multitude of ant species in the U.S., and the effect of contamination from handling (cigarette smoke, colognes/perfumes, soaps) and storage (in pesticide laden areas) on bait acceptance.

- Learning behavior
- Matrix vs active ingredient (use blank bait in testing)
- Aging effect of bait (shelf life)
- Seasonal changes in food preference
- Effect of cigarette smoke and bait storage practices (i.e., pesticide-contaminated baits?)

(4) Additional research on the **proper use of bait types** (i.e., scatter baits, gels, pastes) was deemed important. Use included proper placement (e.g., placement of scatter baits around as opposed to on ant mounds) and studies on optimum granule size for several ant pests. The environmental stability (e.g., how do baits hold up, and thus perform, under varying environmental conditions) of baits was also important.

- Placement
- Particle size
- Weatherability (environmental stability)

(=4) The use of natural product **attractants** (e.g., pheromones as additives to baits) as a means to attract ants to an area and arrest them upon arrival was also discussed. Included in these discussions was research into the isolation, identification, and synthesis of trail pheromones of the major ant pests. Cost of synthesis, however, may exclude the commercial use of some compounds. The volatility, dosages needed for optimum performance, environmental stability, and formulation of volatile attractants was also deemed important.

- Isolation and identification of trail pheromones (attractants)
  - longevity (persistence)
  - active distance, dose/response
  - how are they used most effectively
  - synthesis, stability
  - carriers, formulation
  - species specificity

(=4) Population estimation via development of effective **sampling techniques** was considered important. Reliable sampling techniques would not only provide means for studying the foraging ecology of ants, but also provide researchers the means to more accurately estimate the effect of bait treatments on ant colonies. Some current methods used to estimate ant populations include visual counts, consumption of food resources, input from homeowners (qualitative only), use of fluorescent dyes & electronic sensors, and sticky & pitfall traps. When estimating populations, time of day when sampling is critical, and must be considered when sampling.

- Population estimation

- visual counts (# on trails or mounds)
- consumption
- homeowner input
- time of day
- use of fluorescent dyes
- colony life cycle (% foragers, nurses, etc)
- sticky traps or pitfall traps

(=4) The **distribution of nutrients** (i.e., nutrient flow) within colonies of ants was considered important so as to better understand the flow of (and need for) food (fat, protein, and carbohydrates) and oral toxicants among castes within a colony. Further study of the ability of ants to filter extremely small particles of solid foods was also deemed important. Studies on the distribution of nutrients within a colony might enhance our ability to design delivery systems for baits.

- How far does bait spread? (mark bait & trace it)
- Does bait get to queen? is it filtered?

Research Priority List: German Cockroaches

Discussions on research priorities for German cockroaches were led by Don Reierson and Richard Kramer. The research list that follows is a compilation of ideas deemed important to the study of baiting German cockroaches. The following list of priorities is in descending order of importance (i.e., the most important topic is listed first). Note: The number in brackets at the beginning of each research priority is the number of individuals, out of 20 possible, that voted for the topic during creation of the list.

[20] **Factors affecting bait performance** were considered the most important area of research for baiting German cockroaches. Important areas of research included:

- Why populations plateau after baiting
- How abiotic & biotic factors influence bait performance
- How other treatments affect baiting programs
- How aging of bait influences bait performance
- Sanitation (food & clutter) effects on bait performance
- The influence of formulation, including liquids, on bait performance

[17] The role of German cockroach **nutritional ecology** was considered very important. Some of the more important aspects of German cockroach nutrition that were deemed important areas of investigation were:

- The importance of micronutrients in cockroach foods & baits
- Feeding patterns, seasonality
- Behavior and physiology of feeding
- Nutrition-based population development
- Efficacy of baits as relates to cockroach sex & stage
- Ambient condition (temp, RH, etc..) effect on consumption of foods/baits
- Secondary kill

[16] The **physiology of attraction** of cockroaches to baits and/or foods was considered important. Specific areas of investigation include:

- Distance orientation to foods
- Learned behavior
- Repellency
- Bait placement
- Value of attractants
- Role of pheromones
- Relation to formulation and site specificity

[14] The **evaluation of techniques for monitoring** German cockroach populations was considered important. Specific areas of investigation included:

- Significance of destructive trapping
- Trap type and number used

- Use of attractants
- Trap placement
- Population demographics
- Correlation of trap catch/populations

[13] The potential of **combination strategies** (i.e., bait + additional treatment(s)) for German cockroach control were included. Baits were included as one aspect of the combination. Some of the more specific aspects which were considered important in investigating combination control strategies included:

- The sequence of treatments
- Synergistic effects of multiple treatments
- Which active ingredients and formulations to use
- How would the treatments be spaced (i.e., spatial relationships)

[13] Investigations of existing **bait delivery systems (i.e., bait station design)** was warranted. Particularly, cockroach response to the following variables governing bait station design:

- Chemistry
- Station geometry (i.e., cockroach response to openings)
- Permanent vs disposable stations
- Refillable stations
- Material/texture (i.e., cockroach response to substrates)
- See into
- Other restrictions on design or use
- Non-target design considerations
- Tools, guns, etc...

The final four cockroach research categories were considered only marginally important.

[4] **Correlation of lab and field research**

- Small plot vs large
- Develop more predictive methodology

[3] **Educational programs**

- Technicians
- Customers
- Regulatory personnel
- Researchers/consultants
- How best to apply, limits, safety, etc..

[1] **Develop evaluation techniques**

- Surveys of clients, PCOs, etc...
- Traps
- Food removal
- Electronic, other

[0] **Labeling and label development**

- Develop better language
- Application rate determination
- Fate of leftover bait
- Site-specific labels

Research Funding

A theme throughout the workshop was how to generate a funding base to support the research outlined in the pages above. Items discussed were:

- Comparative funding, consortium, etc...
- Formalization of a research working group, most likely with specific goals or topic areas

This document was prepared by:
Dr. Daniel R. Suiter
Director of the Industrial Affiliates Program
Center for Urban and Industrial Pest Management
Department of Entomology
Purdue University
West Lafayette, Indiana 47907