COMPUTER AIDED DECISION SUPPORT SYSTEM FOR AMERICAN COCKROACH MANAGEMENT IN THE URBAN ENVIRONMENT

NONGGANG BAO AND WILLIAM H ROBINSON
Urban Pest Control Research Center, Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

Abstract—Decision-making for managing household cockroach infestations is a complicated process. Proper decisions concerning cockroach pest management should be made based on the integration of 1) biotic factors, such as pest biology, ecology, and behavior; 2) abiotic environmental factors, such as temperature and relative humidity; 3) target audience's attitude and pest tolerance level; and 4) social, legal regulations, and other constrains. Integrated pest management approaches and designs have rarely been incorporated into the decision-making process of cockroach management programs at the operational level. Lack of decision-making process continues to be a serious impediment to the development and implementation of integrated cockroach management programs in the urban environment. This paper addresses problem-solving techniques using computer-aided knowledge-based system technology for American cockroach pest management programs. Quantification of aesthetic injury level concept is discussed.

A knowledge-based computer decision support system, Management of American Cockroach Decision Aid System (MACDAS), was developed to provide professional pest control operators with expert advice and recommendations, and to assist them making appropriate decisions for American cockroach, *Periplaneta americana* (L.), management. MACDAS was constructed with an intelligent reasoning inference engine, databases with management options, an American cockroach population simulation model, synthesized and expert directed knowledge bases, and user-computer dialog interfaces. Typically, pest control operators input relevant information inquired by the advisory system about the cockroach pest and their associated biotic, abiotic, and other constraints. The system provides ranked recommendations or advice for American cockroach management decision-making to the operator.

INTRODUCTION

The basic principles of integrated pest management (IPM) have been adopted and applied to almost all ecosystems, since the concept of integrated control was first proposed by Stern *et al.* (1959). Consistent with its agricultural origin, IPM concept is defined as "a pest population management system that utilizes all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury" (Smith and Reynolds 1966). The core of the IPM concept has been the decision rule of maintaining pest populations below their economic injury level (EIL).

As the IPM concept is applied to urban ecosystems, new decision rules must be made accordingly (Zungoli and Robinson, 1984). The focus of urban IPM programs must be the interactions between humans and pests, instead of the crop-pest complex in the agroecosystem. An urban IPM program must consider more directly the sociological and psychological needs of the target audience, rather than economic measurements that are standardized in agricultural IPM programs. The aesthetic injury level (AIL) concept was proposed to respond to these needs and to replace the EIL concept for urban ornamental pest management programs (Olkowski, 1974). Zungoli and Robinson (1984), adapted and developed the AIL concept for urban cockroach pest management programs.

Assessment and decision making are the fundamental components of IPM, and characterize state-of-the-art pest management programs in agriculture today (Pedigo and Higley, 1992). However, research on decision-making in urban pest management programs has been behind the advancement in agricultural pest management. Similar to agricultural IPM, decision-making in urban IPM is also a very complicated process. The variables and constrains that must be included in the decision process are extensive. The variability, complexity, and uncertainty of the biotic, abiotic, social, and legal systems in the urban environment can often overwhelm the decision makers. The probability is often very low for making integrated decisions based on the conventional methodologies. Urban IPM decision makers must have system-level tools to help them make integrated decisions, and fulfill the goals of IPM.

Proceedings of the First International Conference on Urban Pests.
K.B. Wildey and Wm H.Robinson (editors). 1993

Computer aided decision-making for IPM program is one of the fastest growing areas in entomological research. Knowledge-based systems, or expert systems, have shown the potential for decision making in IPM programs (Stone, 1989). Knowledge-based systems are artificial intelligence computer programs that solve complex problems by mimicking the problem solving techniques of human experts. They are capable of delivering to decision makers the best and most consistent information for solving difficult problems, and providing the system-level understanding required to make intelligent decisions (Plant and Stone, 1990). In addition, knowledge-based systems have the ability to handle a variety of uncertain information.

The overall objective of this study was to develop a knowledge-based decision support system to help professional pest control operators to make integrated management decisions. The American cockroach, *Periplaneta americana* (L.), was used as the model pest for the system. This pest species is one of the most important and common domiciliary cockroaches in the United States (Piper and Frankie 1978). Outbreaks of this pest in urban environments have not been uncommon (Pinto, 1987). Control strategies for this cockroach usually include the application of residual insecticides to the infested harborages, and the use of toxic bait stations in infested areas.

Basic management decisions were addressed in the system, such as "Do we need any management action now?", if so "What kind of control measures should we take?" If a chemical control option is necessary, then "Which insecticides should be selected for the treatment, or considered as alternatives?".

METHODS AND MATERIALS

This computer decision support system modeled the American cockroach management program for a large apartment complex managed by Roanoke Public Housing Authority (RPHA), Roanoke, Virginia. American cockroaches are seasonal pests in RPHA, and its population reservoirs primarily in the sewer system and apartment basements (Bao and Robinson, 1988). Pest control personnel of RPHA apply insecticides to suppress the population on an irregular basis. Prior to the study reported here, there were no management decisions based on the pest biology and seasonal foraging activity. Chemical control action was solely triggered by tenants' requests, and with no regard for the costs of labor and chemicals. As a consequence, complaint calls were not reduced, and costs for pest control increased.

The Urban Pest Control Research Center (UPCRC) at Virginia Tech and the RPHA established a joint effort to develop an American cockroach management program for the apartment complex in 1989. Based on the previous investigation, apartment basements were identified as the primary reservoir for American cockroach populations (Bao and Robinson, 1988). Monitoring programs were conducted to better understand the seasonal biology and foraging activity in the apartment basements. Caged American cockroach populations were introduced into basements to elucidate the biology of this species in the natural habitat. An American cockroach population simulation model was constructed based on the knowledge obtained through this investigation (Bao and Robinson, unpublished data). The model provided data for predicting basic biological parameters of the American cockroach populations, including seasonal fluctuations and population structure.

The knowledge-based computer decision support system, Management of American Cockroach Decision Aid System (MACDAS), was constructed as a typical knowledge-based system, with three major components: 1) the inference engine, 2) the knowledge base, and 3) the global working memory. The inference engine provides the capability of reasoning and drawing conclusions. The inference engine used in MACDAS was an object-oriented programming shell, Level 5 Object (Information Builders, Inc. New York). The knowledge base component is where all the knowledge, facts, rules, and expertise that relate to the problem solving domain are encoded. The global working memory component is where facts and conclusions that relate to a specific problem solving process are stored. MACDAS also includes an external routine, connected to a database where all the management options were coded, and a simulation model where biological parameters about the target pest species were simulated and generated.

The knowledge representation techniques in MACDAS employed 1) the condition-conclusion, or the IF-THEN logic clause, rule-based reasoning methods; 2) object-oriented programming techniques; 3) and other conventional methods including database and simulation model.

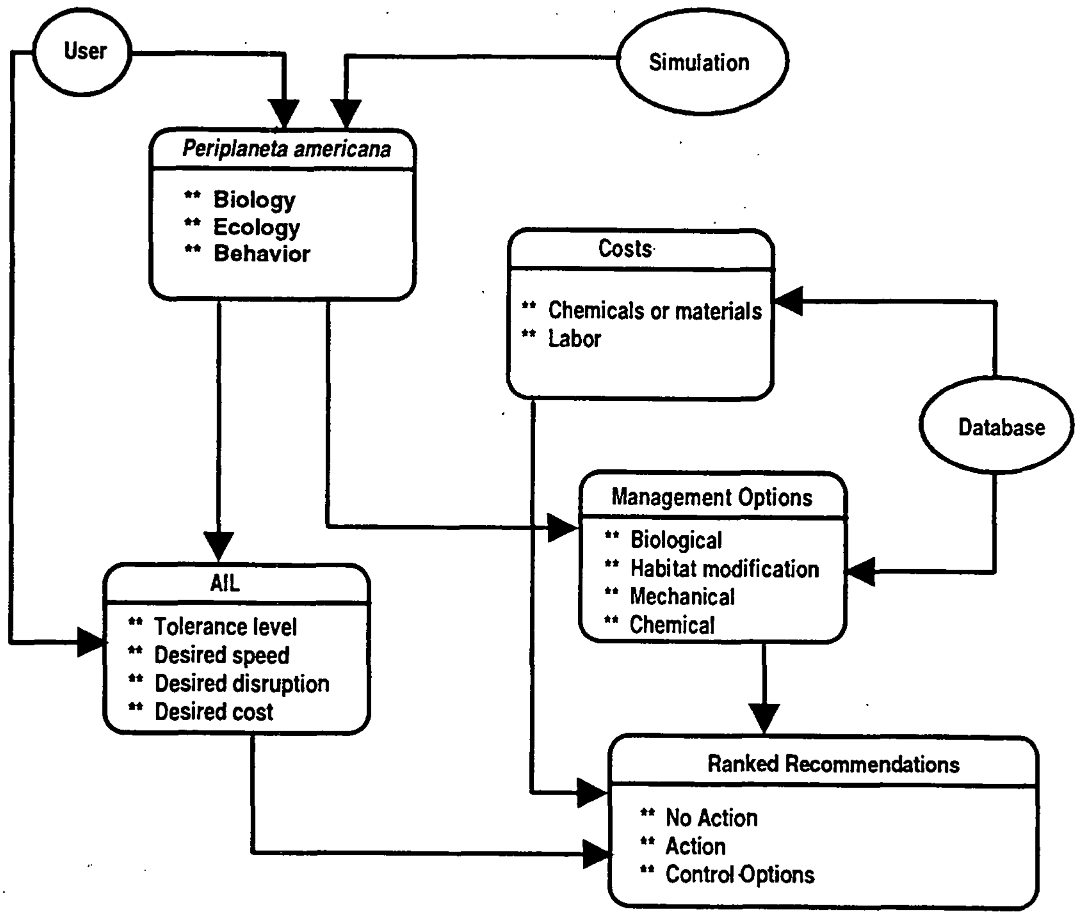

Figure 1. Function model of the MACDAS decision process in determining American cockroach management options. Each box represents a separate decision which must be made before reaching the final conclusions. Information flow required for each decision is represented by arrows.

Forward and backward chaining, the two basic types of a rule-based system, were used extensively in MACDAS. Forward chaining starts with data or observations to reach a conclusion. Backward chaining starts to prove a hypothesis or goal by reasoning backward to test and satisfy its related conditions in the IF clause. The object-oriented techniques in MACDAS provided a more advanced and flexible programming environment. Rule-based reasoning systems were inherited in the object structure.

Background information and knowledge were gathered from three years of research, from published data, and various expert sources on cockroach pest management. Heuristics about the American cockroach and other related constraints were encoded into the knowledge base. Management options and commonly used insecticides were encoded in a database which was embedded in the decision support system.

Quantification of aesthetic injury level was determined by solving the action threshold numerically with a simple statistical model. Data inputted by user about the tolerance levels of the target audience toward cockroach abundance were transformed on a log-probit scale. A linear regression model was then computed to determine the action threshold at a management level specified by the user or the decision maker. The underlying methodology is similar to the computation used in insecticide bioassay.

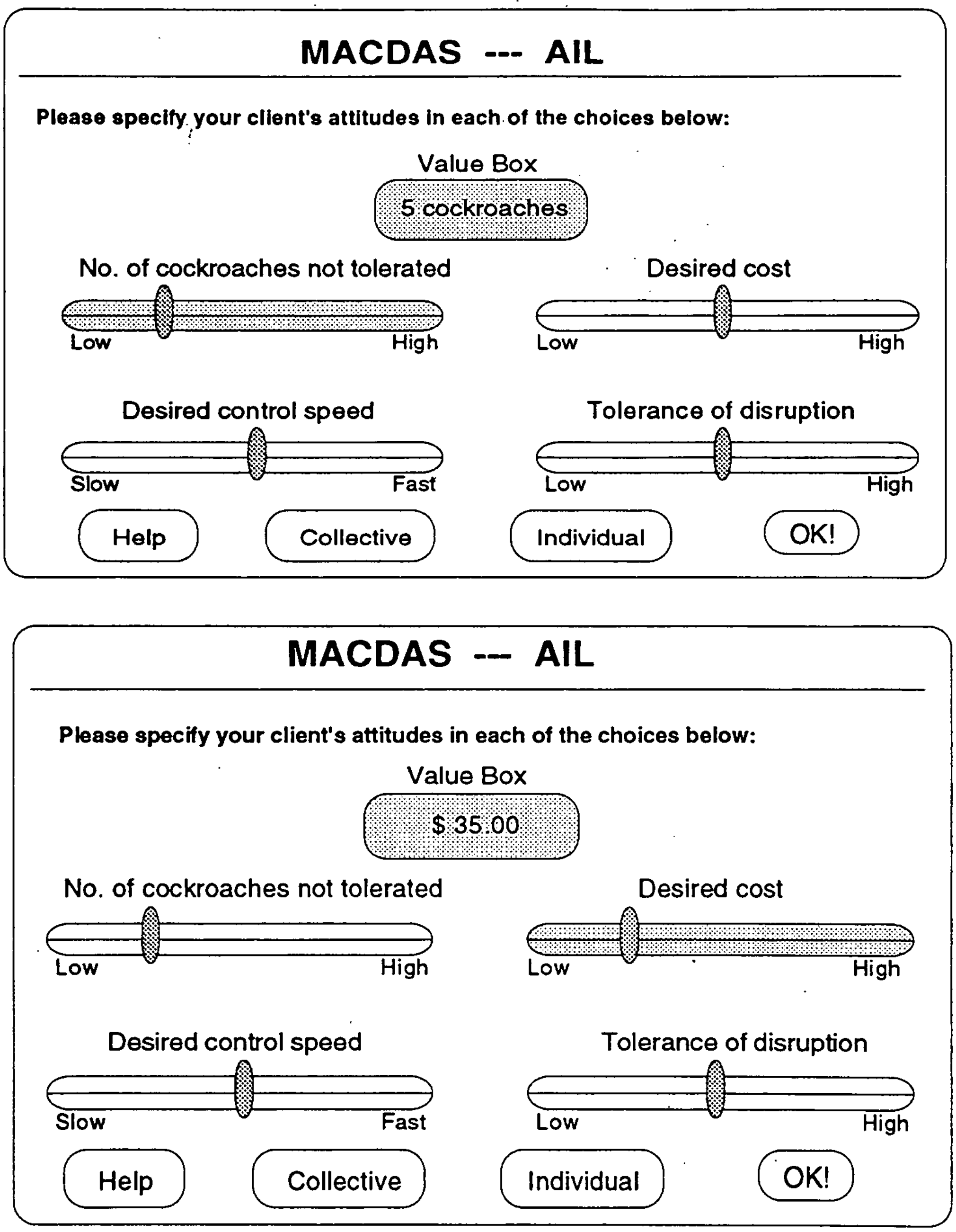

Figure 2. Examples of user-MACDAS interface during the reasoning process in determining the aesthetic injury levle. **Collective** button refers to a group of clients' attitudes are to be entered; **Individual** button refers to a single client's input. **A.** represents an example in which the number of cockroaches is not tolerated by a client; **B.** shows the amount of money a client is willing to pay to manage a cockroach infestation. Desired control speed and tolerance of disruption are entered as qualitative measures, such as very low, low, medium, high, and very high for tolerance of disruption.

RESULTS

The functional model of MACDAS is presented in Figure 1. An end user, i.e. a pest control operator, is requested by the system to input facts and information, such as time of infestation, about a specific American cockroach infestation problem. Data and facts inputted by the user are reasoned in the inference engine by retrieving related rules and reasoning methods in the knowledge base. For example, time of infestation inputted by the user triggers the simulation model to generate the estimated population parameters that are required by the inference process to reach a number of sub-conclusions. The user is further queried by the system to provide target audiences' attitudes about the reported infestation -- the desired cost, control speed, potential disruption of a control process, and the number of American cockroaches that cannot be tolerated (Fig. 2). This input activates the knowledge base to compute the aesthetic injury level, which provides the action threshold for management decisions. The database is activated when the reasoning process calls for screening management options. The knowledge base then compares each of the management options (Table 1) with heuristics in the knowledge base to make ranked recommendations for managing the cockroach infestation.

Determination of the aesthetic injury level in MACDAS was achieved by asking the user to input the relevant attitudes of the target audience towards an American cockroach infestation and control. Specifically, a group of residents were surveyed by the decision maker, the property manager, or pest control specialist. The system queries included 1) the target audience's tolerance level (the number) of American cockroaches seen in a 24 h period; 2) their relative desire as to how soon (days, weeks) the infestation should be corrected ; 3) their tolerance of disruption (from low to high) while a control measure is applied, and 4) their willingness to pay for a pest control action reflected in dollars.

An example of the query screen during the reasoning process of MACDAS is presented in Figure 2 (A, B). Each input reflects a single client's attitude about the cockroach infestation and corresponding control. When all the survey data are entered into the system, MACDAS integrates the data and computes the statistics and mathematical relationship. The decision maker is then inquired to specify a management threshold about the percentile of the clients' responses with respect to the management actions. For example, if the decision maker considers at the 25% level of the total responses as a management threshold for any pest management actions, it fulfills the demands of 75% of the clients who would not tolerate the number of cockroaches seen, and seek a management option. MACDAS computes the corresponding number of cockroaches that reflect the percentile or threshold determined by the decision maker. The computed action threshold, or the number of cockroaches, is compared to the cockroach population foraging density estimated at the time of infestation. If the estimated number of cockroach foragers is greater than the action threshold, treatment options are screened in the reasoning process for management recommendations.

Table 1. American cockroach management options that are commonly used to suppress pest populations are encoded in the MACDAS knowledge base and database.

Category	Options	Encoded
Biological	1. Releasing parasitoids and predators 2. Conserving natural enemies 3. Fungi 4. Nematodes	Knowledge base and Database
Habitat Modification	1. Caulking 2. Sanitation	Knowledge base
Mechanical	1. Trapping	Knowledge base
Chemical	1. Neuro insecticides (organophosphates, carbamates, pyrethroids, etc.) 2. Insect growth regulators 3. Inorganic insecticides 4. Other class of chemicals (slow acting toxic baits, etc.)	Knowledge base and Database

Table 2. An example of MACDAS summary and recommendation report on a hypothetical American cockroach infestation in a large apartment complex.

Date:	06/21/93
Location:	Sundary Apartment Complex, Roanoke, Virginia 400 apartment units
Tenants surveyed:	45
American cockroaches seen within 24 h:	8 (average)
Management threshold:	@20%
Action threshold:	3 American cockroaches
Estimated cockroach foraging density	17 cockroaches/apartment

Status report:
1. American cockroach population is increasing;
2. American cockroach infestations are likely to increase.

Recommendations: – the following treatments are recommended for the situation reported:
1. Immediate suppression is urgent, chemical control needed;
2. Select one of the recommended products for treatment; (A list of ranked chemicals – omitted here)
3. Re-inspect the infested locations in a week.

In addition to the computation of action threshold, user's input about tolerance level of cockroaches are separated into two categories: individual and collective (Fig. 2). Individual refers to the situation of a pest control company dealing with an individual client, such as a homeowner. In this case, the homeowner's perception of the cockroach problem is the action threshold to initiate control. In a large housing complex, determination of the action threshold can be an important criterion for decision-making in cockroach management. By inputting apartment residents' tolerance levels as a group, the decision maker is able to establish a reasonable threshold for cockroach management decision. A hypothetical American cockroach infestation in a large apartment complex in June is summarized in Table 2. Time of American cockroach infestation, survey data, and management threshold were specified into the system. Recommendations of management options were ranked and reported to the decision maker.

DISCUSSION

Urban ecosystems are shaped largely by man's activities. Humans are usually unwilling to cohabit with other organisms besides selected pets and interior plants. Their attitudes and expectations about the quality of life, the environment, pests, and pest management lie beyond the realm of applied biology and ecology. Urban ecosystems are complicated systems as a result of sociological, political, economic, biological, behavioral, and ecological forces. Therefore, an integrated pest management program in the urban ecosystem has its unique characteristics in comparison with that in the agroecosystem. Urban IPM must be redefined as the management system that maintain the pest population level at the minimal interaction between human and pest species. The core of an urban IPM is to minimize client discomfort caused by pests (Stone, 1992).

Research on agricultural IPM has established the economic injury level concept for the decision rule to manage the pest population. For an urban IPM program, the need for urban pest management is driven primarily by sociological and psychological factors such as aesthetics, personal values, community norms, and legal or regulatory pressures. None of these can be as readily quantified as is the EIL. The inability to estimate economic losses caused by urban pests has led to recording the money saved on pesticide reduction as a measure of IPM program success (Wood 1988).

The corresponding concept of aesthetic injury level is currently the best approach for the decision rule for urban IPM programs. The aesthetic injury level concept developed by Zungoli and

Robinson (1984) for a German cockroach pest management program provided the basic guideline for cockroach management decision making. Their approach was to determine the tolerance level of cockroaches by surveying the target audience, and to use this as an aesthetic or action threshold to make management decisions. However, because of the large variability of people's perception, this approach has remained a concept rather than a threshold. Raupp *et al.* (1988) improved this approach quantitatively by plotting the audience survey data into a probability distribution and making a linear estimation at the 50% level as the aesthetic threshold for ornamental pest management decision. However, the linear approximation of the survey data significantly reduced the technical accuracy. The 50% damage threshold may reflect the appropriate decision for ornamental pest management, but its potential of application to other urban IPM decision making is undoubtedly limited.

The computer-aided decision support system presented here inherited the AIL concept as urban IPM decision rule, and developed the techniques that enable to quantify the aesthetic injury level. However, the management threshold is clearly a subjective determination which may be biased depending on the decision maker's integration of economics, personal norms, social and legal considerations, environmental concerns, and other constrains. Further development to better quantify the AIL as an objective threshold remains to be investigated.

Recent studies revealed that allergy to cockroaches is ranked the second most common hypersensitivity among asthmatics, only next to house dust mites. This has composed a significant health threat to approximately 10 - 15 million Americans who are estimated to have developed allergies to cockroaches (Brenner *et al.*, 1990, 1991). If further study can demonstrate and quantify the relationship between human allergic development and cockroach density, it will contribute a more objective action threshold in the decision making process for urban cockroach management programs.

ACKNOWLEDGMENTS

We thank Nicholas Stone, associate professor of entomology at Virginia Tech, for his help and assistance in the design and development of the knowledge-based system. We are grateful to Forshaw Distribution, Inc. for sharing their chemical product database, and to the staff and residents of Roanoke Redevelopment and Housing Authority for their long-term cooperation of cockroach management programs.

REFERENCES

Bao, N. and Robinson, W. H. (1988). Treating for Americans. *Pest Control* 56(11): 62-64.

Brenner, R.J., Barnes, K.C., and Helm, R.M. (1990). Arthropod allergies in the urban environment. *Proc. National Conf. Urban Entomol.* pp. 57-66.

Brenner, R.J., Barnes, K.C., Helm, R.M., and Williams, L. W. (1991). Modernized society & allergies to arthropods. *American Entomologist.* 37(3): 143-155.

Olkowski, W. (1974). A model ecosystem management program. *Proc Tall Timbers Conf. Ecol. Anim. Cont. Habitat Manage.* 5: 103-117.

Pedigo, L.P. and Higley, L.G. (1992). The economic injury level concept and environmental quality: A new perspective. *American Entomologist.* 38(1): 12-21.

Pinto, L. (1987). Battling American roaches. *Pest Control* 55(8): 40, 41, 44, 48.

Piper, G. L. and Frankie, G. W. (1978). Integrated management of urban cockroach populations. In: *Perspective in urban entomology* [Frankie, G. W. and Koehler, C. S. eds.]. pp. 249-266. Academic Press, Inc. New York.

Plant, R.E. and Stone, N.D. [eds.]. (1990). Knowledge-Based Systems in Agriculture. McGraw-Hill, New York. 364 pp.

Raupp, M.J., Davidson, J.A., Koehler, C.S., Sadof, C.S., and Reichelderfer, K. (1988). Decision-making considerations for aesthetic damage caused by pests. *Bull. Entomol. Soc. Am.* 34(1): 27-32.

Smith, R.F. and Reynolds, H.T. (1966). Principles, definitions and scope of integrated control measures in Baden-Wurttemberg, West Germany. *Z. Angew. Entomol.* 77: 398-401.

Stern, V.M., Smith, R.F., Bosch, R. van den, and Hagan, K.S. (1959). The integrated control concept. *Hilgardia.* 29: 81.

Stone, N.D. (1989). Knowledge-based systems as a unifying paradigm for IPM. In: *Proc. National IPM Symp.* pp. 13-24.

Stone, N.D. (1992). Expert systems and decision making for urban IPM. *Proc. National Conf. Urban Entomol.* pp. 5-16.

Wood, F.E. (1988). Urban pest management. *Proc. National Conf. Urban Entomol.* 2: 5-13.

Zungoli, P.A. and Robinson, W.H. (1984). Feasibility of establishing an aesthetic injury level for German cockroach pest management programs. *Environ. Entomol.* 13: 1453-1458.