DEVELOPMENT OF AN INTEGRATED CONTROL PROGRAM FOR THE EASTERN SUBTERRANEAN TERMITE - Interim Report

January - August 1987

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ABSTRACT

The eastern subterranean termite, Reticulitermes flavipes (Kollar), is a serious economic pest in southern Ontario. Annual costs of termite control and damage repair in Ontario are estimated in excess of $1,000,000. In 1987, an ongoing research project entitled "Development of an Integrated Control Program for the Eastern Subterranean Termite" was initiated in the Faculty of Forestry, University of Toronto. This project is based on recognition of unique environmental, physical, and social aspects of urban Ontario, and apparent differences in the biology and behaviour of R. flavipes at the northern limits of its geographic distribution. The goal of the project is to substantially advance the development and implementation of safe, effective, and environmentally acceptable methods of subterranean termite control through basic and applied research and extension efforts.

This interim report describes progress during the first eight months of the project, and contains the project Operating Plan. Proposed research in the promising areas of subterranean termite behaviour, environmental biology, and associations with fungi and nematodes is described, as is the incorporation of anticipated results into a termite management program. Successful implementation of such a program will require educational efforts based on sociological as well as biological research findings.

ACKNOWLEDGMENTS

We are grateful to the following sponsors for their participation and financial support of this project:

Borough of East York
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City of Toronto
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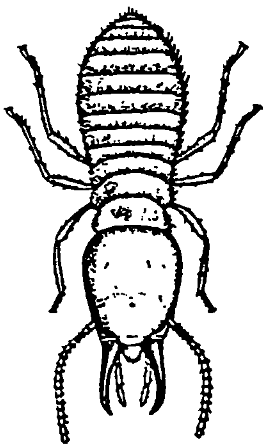
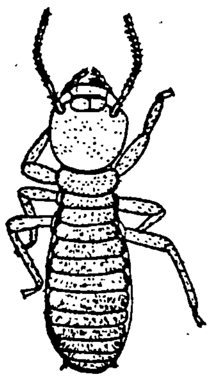
Toronto Real Estate Board
Town of Dresden

The views expressed in this report are those of the author, and the sponsors accept no responsibility for them.





INTRODUCTION

The research project entitled "**Development of an Integrated Control Program for the Eastern Subterranean Termite**" was initiated in January 1987, within the Faculty of Forestry at the University of Toronto. The purpose of the project is to investigate and transfer new information on the biology, behaviour and control of the eastern subterranean termite, Reticulitermes flavipes (Kollar), in Ontario in order to develop a safe and effective termite management program. The emphasis is on developing alternative, environmentally compatible methods of termite detection and control that will reduce pesticide usage in the urban environment. Phase I of the project extends from January 1987 through December 1991, and includes field and laboratory research and professional and public awareness components. This interim report is issued to note progress during the first eight months and to describe the project operating plan.

BACKGROUND

Severity of the Termite Problem in Ontario:

The eastern subterranean termite, Reticulitermes flavipes (Kollar), is an extremely destructive and costly structural pest that has now been found in 28 Ontario municipalities (Cutten, 1987; Grace, 1987a). It was first reported in the southernmost portion of the province at Point Pelee in 1929 (Kirby, 1965). Following this, subterranean termites were found damaging a building on the Toronto waterfront in 1938, apparently as the result of an introduction by ship from the United States around 1935 (Urquhart, 1953). Movement of infested wood and topsoil is thought to have spread the infestation throughout the urban areas of southern Ontario.

The spread of subterranean termite infestation through southern Ontario has been both rapid and costly. The Ontario Ministry of the Environment currently administers $500,000 annually in grants to homeowners to control termite infestations. These grants cover a maximum of only 60% of direct control costs, cover little of the costs of repairing damaged buildings, and do not include those treatments and repairs handled exclusively by private contractors. Municipal grants are also available to homeowners. Thus, the direct annual costs incurred in Ontario as a result of termite infestation can be estimated in excess of $1,000,000.

Problems With Current Termite Controls:

Currently, subterranean termites are controlled by injecting the soil below and around buildings with broad-spectrum pesticides. This is known as the "chemical barrier" approach, and requires over 100 gallons of pesticide solution to treat an average structure.

The cyclodiene (chlorinated hydrocarbon) insecticides aldrin, chlordane and dieldrin are used in such soil treatments in Ontario. Although these compounds may provide residual protection against termites for over 30 years (McEwen and Madder, 1986), there is increasing public concern over the possible deleterious effects of these persistent and non-selective pesticides on human health and the environment (cf. Hess, 1987; Shabecoff, 1987). Although it is subject to debate, a great deal of evidence on these deleterious effects, including possible carcinogenicity, has been presented (New York State Dept. of Environmental Conservation, 1986). In the United States, sales of chlordane/heptachlor termiticides were voluntarily suspended by the sole manufacturer (Velsicol Chemical Corp.) in August 1987 (Moreland, 1987). Use of these pesticides is banned in Massachusetts and New York, and concerns over public health have been raised in Ontario by the Medical Officer of Health of the City of Toronto (Neighbourhoods Committee, 1986).

Public concerns about broad-spectrum pesticides have forced those who recommend or apply these materials to face increasingly serious questions of legal liability for their use and misuse. Pest control operators have experienced sharp increases in the costs of liability insurance - costs which are ultimately borne by the consumer in the form of higher treatment costs. The costs to private contractors pale beside the potential costs to public agencies for court-mandated environmental clean-ups or public health monitoring.

Moreover, these pesticides are currently neither imported nor manufactured in Canada, and little stock remains (G.M. Cutten, pers. commun.). An alternative soil insecticide (chlorpyrifos) is available, and several other compounds are awaiting registration. However, the shorter lifetime and higher cost of these insecticides may limit their utility as direct replacements for the cyclodienes. Since these are also broad-spectrum poisons and the technique of soil treatment remains the same, the newer soil chemicals also inherit the negative public image and high insurance costs associated with use of the cyclodienes.

An additional concern with "chemical barrier" soil treatment is that by excluding termites from the structure without necessarily killing an outlying colony, termites may simply be forced to forage on adjacent properties. Since termite detection relies on visual inspection, such infestations can go unnoticed for years behind basement wall coverings, resulting in serious structural damage.

Thus, the "chemical barrier" approach to subterranean termite control, although historically effective, is now encumbered by: (1) increasing public health and environmental concerns, (2) an increasingly negative public image, (3) increasing liability and legal actions, (4) increasing insurance, material, and treatment costs, (5) decreasing availability of these persistent pesticides, and (6) questions of overall efficacy when homes are treated as part of a community-wide eradication effort.

Need for New Approaches to Termite Control:

The continuing need for safe, efficacious termite control necessitates the development of new approaches to controlling these damaging insects, rather than simply exchanging broad-spectrum pesticides in the "chemical barrier" approach. These new approaches must take into account the potential public health, environmental, legal, and financial consequences of pest control methodology, and must be appropriate for use in urban settings with closely spaced structures.

PROGRESS REPORT

Phase I of the project is intended as a five year research program. Goals for the first year are familiarization with the nature and extent of the termite problem in Ontario, establishment of appropriate research facilities, review of existing knowledge and establishing appropriate contacts, and development of the project operating plan. In the first eight months we have made excellent progress towards all of these goals.

Specific accomplishments to date include:

a. Acquisition of reference materials, including books, abstract services and technical journals not generally available in University library collections or elsewhere in Ontario. This information base is essential to keep abreast of developments in termite research and control technology, to address inquiries from the public and professionals involved in termite control, and to develop research and educational programs. The project is envisaged as a unique Canadian information resource.

b. Establishment of laboratory facilities at the University of Toronto, where several experimental termite colonies are currently maintained.

c. Field observations of termite activity in metro Toronto, Guelph and Kincardine, and identification of experimental field sites.

d. Selection of an Advisory Committee (Appendix I) to monitor research progress and advise on fundraising. The Committee is chaired by Mr. Donald M. Baxter, Executive Director of the Economic Development Division, Municipality of Metropolitan Toronto, and represents a diverse group of interested parties. The first Advisory Committee meeting will be held this fall.

e. Consultations on specific problems with municipal building inspectors, the Hazardous Contaminants Coordination Branch of the Ontario Ministry of the Environment, Forintek Canada Corporation, pest control operators, builders, the Royal Ontario Museum, homeowners, various industrial representatives, and the press. This extension function (information transfer and information exchange) is a valuable component of the project.

f. Establishment of appropriate contacts through attendance at professional and scientific conferences held in Ontario. The Director delivered the keynote address discussing new directions in pest control to the annual meeting of the Canadian Wood Preservation Association; and an invited address reviewing termite research and control in Canada to the International Research Group on Wood Preservation, in a joint meeting with the International Union of Forestry Research Organizations (IUFRO).

g. Assistance in training municipal building inspectors. A five-session training course in June on the biology and control of wood destroying organisms was attended by building inspectors from Toronto, Guelph, Mississauga, North York, Scarborough, and the Ontario Ministry of the Environment. Invitations were extended to all of the municipalities contributing to the project at that time, and favorable reviews were received from those in attendance.

h. Establishment of contacts and discussion of cooperative projects with scientists in other Canadian and international universities and research organizations. On the international level, this includes researchers in the United States, Australia, Germany, and Japan.

i. Providing information to the public via feature newspaper articles in The Toronto Star (Miller, 1987) (Appendix II) and The Globe and Mail (Hess, 1987) (Appendix III), radio interviews, and an appearance on the national television program "Canada AM."

j. Completion of a pilot survey of public attitudes and information on termite control in selected urban areas this summer, in cooperation with the Hazardous Contaminants Coordination Branch of the Ontario Ministry of the Environment. Results of this survey, and additional such efforts, will be used to shape the direction of future research and develop effective public information programs.

k. Submission of research proposals to several competitive grants programs.

l. Publication of a technical report and two review articles:

Grace, J.K. 1987. Termites in eastern Canada: a brief review and assessment. The Inter. Res. Group on Wood Preserv. Document No. IRG/WP/1333. (Appendix IV)

Cooper, P.A., and J.K. Grace. 1987. Association of the eastern subterranean termite, Reticulitermes flavipes (Kollar), with living trees in Canada. J. Entomol. Sci. 22(4): 353-354. (Appendix V)

Grace, J.K. 1987. The challenge of wood destroying insects. Proc. Can. Wood Preserv. Assoc. in press (Appendix VI)

m. Development of an operating plan for the project.

PERSONNEL

The Project Director, Dr. J. K. Grace, was appointed to that position in January 1987. Dr. Grace received his doctoral degree in entomology from the University of California at Berkeley in 1986, for research on the chemically mediated behaviour of the western subterranean termite, _Reticulitermes hesperus_ Banks. This close relative of the eastern subterranean termite is a serious pest in the western United States and southern British Columbia. In addition to academic employment, Dr. Grace has experience in construction and commercial termite control. He has authored or co-authored two dozen technical and semitechnical articles in the fields of urban and forest products entomology.

Four other members of the Faculty of Forestry have spent a portion of their time on project-related matters this year, and will continue to participate as cooperating faculty: Professors J. R. Carrow, P. A. Cooper, M. Hubbes, and D. N. Roy. Professor Carrow, Dean of the Faculty, is a forest entomologist with extensive experience in the development and implementation of biological control. Professor Cooper, a wood scientist active in preservation research, has participated in termite research in Ontario over the last decade, including a large-scale survey of termite activity in trees in Toronto. Professor Hubbes, a forest pathologist, was instrumental in initiating the research project on subterranean termites and directs an active research program stressing genetic aspects of insect and fungus biology and control. Professor Roy is currently involved in many aspects of wood, natural products and environmental chemistry, including research on the degradation and persistence of pesticides and other environmental contaminants. The active participation of these faculty members and their respective technical staff and students is an enormous asset to the project.

Financial management, secretarial and office services are provided by Faculty staff. Ms. Chris Wilhelm is employed as project secretary on a 40% basis. Students employed by the Ontario Ministry of the Environment administered the pilot survey of public attitudes and information this summer, in conjunction with inspections for termite activity. In the coming months, we plan to employ a full-time laboratory technician, several postdoctoral associates, and part-time student research assistants.

FACILITIES

The Faculty of Forestry maintains the project office and entomology laboratory facilities on the St. George campus of the University of Toronto. Entomology laboratory space was assigned in late Spring 1987, and is now in use, although equipment installation and renovations are still in progress. Pathology, wood science, and chemistry laboratories are also maintained by the Faculty on the St. George Campus. Specialized laboratory, analytical, and computing equipment are available for use in these facilities.

Equipment currently in operation or undergoing installation includes: humidity and temperature controlled incubators, fume hoods, positive pressure hoods, drying oven, kiln, Shimadzu capillary and packed column gas chromatograph, Mettler dual-range analytical balance, Beckman gradient HPLC, personal computers, and Faculty wood shop and material testing equipment. Campus GC-MS and HPLC-MS facilities, and mainframe computer facilities are also readily accessible.

University of Toronto

FACULTY OF FORESTRY

DEVELOPMENT OF AN INTEGRATED CONTROL PROGRAM
FOR THE EASTERN SUBTERRANEAN TERMITE

INTERIM FINANCIAL STATEMENT
1 January 1987 - 31 August 1987

INCOME

City of Toronto	100,000	
City of Etobicoke	10,000	
City of Guelph	7,655	
City of North York	11,200	
City of Hamilton	25,000	
Borough of East York	5,000	
Town of Dresden	247	
Canada Mortgage and Housing Corporation	15,000	
Toronto Real Estate Board	1,000	
Ont. Real Estate Assoc. Foundation	2,500	
G. C. Metcalf Foundation	10,000	187,602

EXPENDITURES

1.	Salaries		
	Project Director	33,750	
	Secretary (40%)	5,324	39,074
2.	Benefits		
	Project Director	5,446	
	Secretary	425	5,871
3.	Equipment		
	Filing cabinet	210	
	Computer/Printer	14,068	
	Environmental cabinet	5,905	
	Fumehood (incl. installation)	11,576	
	Hygrometer and lamps	1,311	
	Balance, vacuum pump, drying oven	5,240	
	Refrigerator	741	39,051

4.	Supplies			
	Laboratory supplies	2,834		
	Computer supplies	1,095		
	Reference materials (books, subscriptions, reprints)	2,046		
	Literature searches	186	6,161	
5.	Travel (Meetings, Seminars, Field Work)			
	Ontario Pest Control Seminar, Feb.	160		
	Can.Wood Preserv.Assoc., March	100		
	American Wood Preserv.Assoc., May	111		
	IUFRO Int.Res.Group on Wood Pr.,May	1,189		
	Field Work, Toronto	52	1,612	
6.	Other			
	Office supplies and postage	143		
	Long distance calls	91		
	Courier	139		
	Xerox	262	635	
7.	University Overhead			
	25% of 1, 2, 4, 5, 6	13,338		
	0% of 3	-	13,338	105,742
BALANCE				81,860

I. Jardine
Manager, Finance
and Administration

OPERATING PLAN

Intent of the Project:

The rationale for the project and its general framework and focus have been defined in two documents previously issued by the Faculty of Forestry: "Rationalization of Research and Policies for Control of the Subterranean Termite" (Cooper and Morris, 1981), and "Development of an Integrated Control Program for Control of the Eastern Subterranean Termite in the Urban Environment" (Faculty of Forestry, revised 1986). The purpose of this operating plan is not to repeat these documents, but rather to detail the objectives and proposed research and educational activities during Phase I of the project.

Currently, subterranean termite infestation is increasing in Ontario, is difficult to detect, and is controlled by the application of large amounts of persistent pesticides to the soil. The overriding objective of this project is the development of alternative, environmentally acceptable methods of subterranean termite control, and implementation of these methods in an integrated management program that will reduce pesticide usage in the urban environment. Thus, both biological and sociological concerns must be addressed.

Structure of the Project:

The history of subterranean termite research and control efforts in Ontario is reviewed in Appendix IV, under the title "Termites in Eastern Canada: A Brief Review and Assessment." In order to channel past and present research efforts into the development and implementation of an integrated management program, this project must pursue more than a single promising research direction. The project must be both a centre of provincial research activity, a centre for exchanging information with other research groups, and a centre for transferring information to practitioners and the public. In addition, goals and methodology in the first five-year phase must remain flexible enough to permit collection of a variety of information about R. flavipes in Ontario, exploration of a variety of research areas, and to take advantage of new developments in the course of this period.

The functional organizational structure of the project can be summarized as follows:

I. Biological Investigations

   A. Behaviour and Behavioural Control

   B. Environmental Biology and Susceptibility

   C. Biological Control

   D. Multi-tactic Control

II. Information Transfer and Exchange

A. Research

a. Characterization of public attitudes, information, and information sources

B. Implementation

a. With specific audiences (e.g., building inspectors)

b. With the urban public

In Phase I of the project, a series of interrelated research projects will be initiated in each of these areas of interest. The rationale, goals, and methodology for each of these subprojects is discussed below. It is expected that these projects will be expanded upon and supplemented by additional investigations as permitted by preliminary results, new scientific developments, and availability of funding.

I. Biological Investigations:

A. Behaviour

Subterranean termite workers are blind and dwell in an environment with few environmental cues available to them. Chemical communication is thus extremely important both in locating food materials and in maintaining the social integrity of the termite colony (Stuart, 1969). Termites are very susceptible to any modification of their "chemical environment." For example, exposure to compounds mimicking natural termite hormones interferes with individual growth and development and with colony social organization (Haverty and Howard, 1979); compounds normally used by termite workers to mark their foraging trails can be artificially applied by experimenters to direct termite travel in a particular direction (Grace et al., 1988); and compounds found in certain plants can be applied to otherwise susceptible food materials to inhibit termite feeding (Grace et al., 1986) and to repel termites (Grace et al., submitted).

Modification of termite behaviour, use of their own chemical and other environmental cues against them, thus offers a promising alternative to broad-scale soil poisoning. In fact, in many areas of pest control, the use of behavioural chemicals is currently recognized as a safe and effective alternative to standard pesticide treatments (Grace, 1987b; Lewis, 1981; Mitchell, 1981). Unlike broad-spectrum pesticides, compounds that modify insect behaviour have proven to be highly selective in their actions, with low human toxicity and no adverse environmental impact (Ritter and Persoons, 1976; Wood, 1980).

Compounds in resistant woods that repel termite attack have been of some interest for many years (Wolcott, 1924), as has the concept of attracting and arresting foraging subterranean termites at strategically placed toxic baits (Esenther et al., 1961; Esenther and Beal, 1979). In fact, the potential efficacy of controlling subterranean termites by encouraging them to feed on small wooden blocks decayed by an attractive fungus (Gloeophyllum trabeum) and impregnated with a non-repellent pesticide, known as the "bait block" method, was demonstrated in Ontario field tests by Ostaff and Gray (1975). However, the demonstrated efficacy, ease of unskilled application and low cost of the conventional soil poisons has long precluded commercial interest in alternative methods.

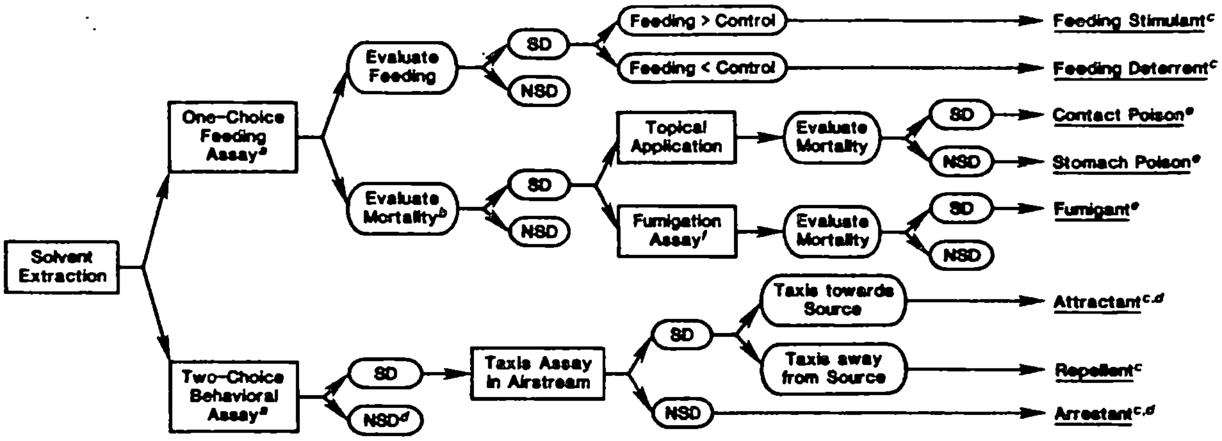
As described in the **Background** statement, problems with the continued use of conventional pesticides for termite control have become apparent. As a result, there has been a resurgence of scientific interest in developing alternative control methodologies based upon termite behaviour (Esenther, 1985a; French and Robinson, 1984; Jones, 1984; Su et al., 1982). Prerequisite to this is the need to increase and refine our understanding of chemically mediated termite behaviour (LaFage, 1987). Recent investigations of subterranean termite orientation (Grace et al., 1988), foraging (Cooper and Grace, 1987), and feeding behaviour (Grace et al., 1986; Grace et al., submitted) were conducted from this point of view.

In the remaining four years of Phase I of the project, we plan a comprehensive investigation of the applicability of behavioural chemicals to subterranean termite control. This will consist of (1) isolation of termite repellents and arrestants/attractants from trees and fungus infected wood in southern Ontario; (2) preliminary investigations of termite trail pheromones, colony recognition mechanisms, and pheromonal mechanisms controlling colony development and social organization; (3) measurement of the effects elicited by behavioural chemicals in individual termites of different castes and developmental stages, and in groups of different composition and size; (4) efficacy of paper pulp baits formulated with an attractant and either a slow-acting toxicant, an insect growth regulator, or a biological agent to suppress feeding and elicit mortality in termite groups of different size and composition; (5) use of repellents to enhance the efficacy of attractant baits; (6) application of insecticidal dust formulations to termite colony members as a means of nest eradication.

This emphasis on termite behaviour will complement research efforts currently underway worldwide (eg., in Australia, Japan, and the United States), and we will therefore be in a position both to incorporate advances elsewhere into our research program and to contribute results in Ontario to the global initiative (cf., Lenz et al., 1987). It must be borne in mind that techniques developed elsewhere in the world will need modification for transfer to Ontario due to differences in climate, building construction, soil types, and the biology and behaviour of local populations of R. flavipes (Husby, 1980; Cooper and Grace, 1987).

In year 1 of the project we have initiated field observations, review of relevant literature, and experimental collection and culturing of termites. With respect to the investigations of termite behaviour outlined above, much of year 2 will be spent in "fine-tuning" collection and maintenance methods, and developing appropriate biological assays (bioassays). Although reference techniques for termite collection (LaFage et al., 1983; Su and Scheffrahn, 1986; Tamashiro et al., 1973) and maintenance (Grace, 1986; Lenz et al., 1987) are available, some modification is always necessary to accommodate specific conditions (Lenz et al., 1987). Similarly, although a general scheme (Figure 1) to assess the effects of behavioural chemicals and toxicants on subterranean termites has been developed in previous work (Grace et al., submitted), each specific assay in this general scheme must be validated or modified to fit Ontario R. flavipes.

Figure 1. General sequence of bioassays for laboratory evaluation of the effects of materials on termite behaviour and survival. Rectangles indicate procedures or tests; ovals indicate results. SD = significant difference from control; NSD = no significant difference.



[a]See description of assays in text and in Grace et al. (1986).

[b]Compare mortality at 5, 15, and 45 days (log-time series).

[c]For methods used to isolate and identify semiochemicals see Silverstein (1970, 1977). Establish dose-response curve. Conduct biosynthesis and receptor physiology studies.

[d]Assay for trail-following response.

[e]Establish dose-response curve. Study mode of action including antibiosis.

[f]Confine in vicinity of treated substrate (without contact) and compare to starvation control.

It will also be necessary to develop a number of entirely new bioassay procedures. In contrast to other termite-infested geographic locales, the relatively short warm season of peak termite activity in Ontario necessitates the development of laboratory simulations of field conditions to test techniques and materials, similar to those developed in Germany at the Bundesanstalt fuer Materialpruefung (BAM). In addition, the proposed emphasis on the contribution of individual termites to group behaviour is a new area of research and demands new techniques.

Due to the high level of social cooperation among termites, the termite colony is frequently viewed (and treated in bioassays) as a "superorganism" (Emerson, 1939; Wilson, 1971). Indeed, the fact that a termite colony is actually a collection of interacting individuals of different ages, different castes, and different stages of development is relatively unimportant in assessing the efficacy of a broad-spectrum pesticide intended to be applied in large quantities to the soil. However, the actions of these different individuals are crucial in determining the efficacy of more specific control methods intended to modify or take advantage of termite behaviour. The most recent investigations of the use of hormone-mimicking insect growth regulators stress that differences among the individuals comprising the colony cannot be ignored (Tsunoda et al., 1986).

Grace et al. (submitted) measured the behaviour of individual termites exposed to repellents and attractants by labour-intensive direct observation. However, this method was time consuming and applied only to bioassays with individual insects, since it was not feasible for accurately observing the actions of individuals within a larger social group of termites. Microcomputer controlled video image analysis now makes this possible .

Video image analysis of insect locomotor behaviour involves successive digitization of a large number of video frames, and is thus an extended application of single-frame video digitization and analysis systems, such as that used by Grace et al. (1986) to measure termite feeding on paper. A basic commercial system with video camera, video recorder, digitizer, monitor, microcomputer and software (Videomex, Columbus Instruments International Corp.) is available, and additional software and systems modifications have been developed by several researchers (Dusenbery, 1985a, 1985b; Royce-Malmgren and Watson, 1987). These systems will permit either automated or user-cued microcomputer analysis of the movement of individual animals, groups of animals, and individuals within groups. Automated analysis of the behaviour of an individual in a group is possible if the individual can be differentiated from the group, with a marker dye (Su et al., 1983) for example. However, user-cued analysis of a recorded video sequence (Royce-Malmgren and Watson, 1987) should allow separate measurements of the actions of all of the individuals making up a given group of termites.

In the coming year, installation and modification of the image analysis system will be followed by the development of useful bioassays, following the general scheme presented in Figure 1. Behavioural chemicals to be evaluated will be selected from four sources: (1) plant materials suspected to be either resistant or susceptible (Cooper and Grace, 1987; Grace et al., submitted); (2) fungus-decayed woods from field collection in southern Ontario, and from cultures previously identified as exerting behavioural effects (Amburgey, 1979); (3) termite glandular secretions (pheromones); (4) compounds identified through literature review or current research developments. These materials are administered in behavioural bioassays by impregnation of sapwood wafers, papers, or pressed paper pulp "baits" (Esenther, 1985b).

The decay fungus <u>Gloeophyllum</u> <u>trabeum</u> produces a compound inducing trail-following in <u>R.</u> <u>flavipes</u> (Esenther et al., 1961). Compounds produced by the actions of other decay fungi also attract termites, arrest their movement, or induce trail-following (Amburgey, 1979; Grace and Wilcox, in preparation; Smythe et al., 1967). This observed "preference" for wood decayed by particular fungi was the basis of the bait-block approach to attracting and controlling foraging termites (Esenther and Beal, 1974, 1979; Ostaff and Gray, 1975). Isolation of additional fungi from termite-infested wood in Ontario is likely to result in the identification of other attractants.

Wood of tree species suspected from previous work (e.g., Cooper and Grace, 1987; Grace et al., submitted) to contain compounds eliciting behavioural effects in subterranean termites will also be sources of bioassay material. Chemical isolation of these compounds will follow the sequential procedures discussed by Silverstein (1970, 1977).

Chemical compounds produced by the insects themselves (pheromones, or intraspecific chemical messengers) (Karlson and Lüscher, 1959; Birch and Haynes, 1982) are also worthy of investigation. Specifically, trail pheromones used in orientation (Grace et al., 1988), defensive compounds secreted by termite soldiers (Prestwich, 1984; Zalkow et al., 1981), chemicals responsible for colony recognition (Clément, 1986), and pheromones passed within the colony controlling the development of individuals into certain castes or body-forms (Lefeuve and Bordereau, 1984; Bordereau and Han, 1986) are potentially useful in pest management technology. We will initiate preliminary investigations of these materials via isolations from glandular material and head-space analyses of volatiles. However, the limited information available and the need to develop effective pheromone collection and bioassay techniques precludes further speculation at this time on specific methodology and practical application.

Once bioassays are established, baseline behavioural information collected, and likely repellents and attractants evaluated, the actual control agents will be introduced to the investigations via impregnation in the attractive bait. Slow-acting toxicants (Esenther, 1985c; Su et al., 1987), insect growth regulators (Jones, 1984), and biological control agents (see below) are all worthy of evaluation. Currently, the most promising materials appear to be growth regulators such as fenoxycarb (Maag Agrochemicals Inc.) which interfere with normal insect growth and development (Jones, 1984), although a fungal toxin (Esenther, 1985b) and several experimental compounds (personal communications to J.K. Grace) are also of interest. This technique demands that the candidate control agent be non-repellent and slow-acting to permit its spread throughout the colony (Su et al., 1987).

In addition, the use of a repellent application to susceptible food materials to direct termite foraging toward attractant baits will be incorporated into the project. This synergistic concept is explored below under the heading "**Biological Investigations: Multi-tactic Control.**"

A last behavioural aspect which must also be explored in order to develop a synergistic prescription for termite control is the application of the control agent in the form of a dust (powder) to foraging termites "captured" by an attractant bait. This modification of an old control technique for wood-inhabiting insects relies upon the mutual grooming behaviour of social insects to distribute the control agent throughout the colony, and is currently proving effective in Australian field tests (J.R.J. French, pers. commun.). This demands a control agent similar to those employed in the bait-block method of control discussed above, and uses similar small quantities of the active material. Thus, like the baiting technique, "dusts" applied in this manner are cost-effective with little probability of general environmental contamination. This last aspect of behavioural investigation is therefore compatible with the attractant/repellent studies outlined above.

I. Biological Investigations:

B. Environment

The eastern subterranean termite is distributed across a large and climatically diverse geographic area: from the southern tip of Florida, through the southern and eastern United States, and as far north as Wisconsin and Ontario. For an insect found predominantly in more temperate areas of North America, the relatively harsher climate at the northern limits of its distribution must be stressful. Certainly, it forces R. flavipes into certain seasonal adaptations (Esenther, 1969; Husby, 1980).

Currently, there is very little information available on the mechanisms employed by termites and ants to survive cold winter weather (Tauber et al., 1986). The observations that have been made indicate that R. flavipes moves out of exposed surface wood and below the frostline in the soil (Banks and Snyder, 1920), but may continue to inhabit the interior of large pieces of wood above ground such as logs and stumps (Husby, 1980; Wilson, 1971). Husby (1980) found no evidence of physiological adaptation to cold temperatures via changes in hemolymph content ("antifreeze") in overwintering Ontario termites, although he did report a seasonal reduction in egg production and in the number of dependent larvae and reproductives found in overwintering colonies. Husby (1980) did, however, find a significantly lower laboratory survival rate among termites collected in the winter than among those collected in the warm season. What evidence there is supports the idea of a behavioural adaptation to winter physiological stress.

Investigation of R. flavipes winter survival is important for two reasons: (1) understanding and prediction of the spread of termite infestation in Ontario; and (2) the possibility of interfering with behavioural adaptations or applying additional stress to overwintering populations to achieve control. With the development of proper application methods, a circumscribed and quiescent overwintering colony may be more susceptible to pathogens and toxins than an active and widely distributed summer colony.

In this project, laboratory studies of the effects of temperature and humidity (in controlled incubators) will be coupled with measurement in the field of temperature, humidity, and termite foraging activity at different soil depths through the winter. A likely protocol is to employ field monitoring with thermocouples (French et al., 1987) at bait stations modified after that described by Su and Scheffrahn (1986). Placement of wood or boxboard within jointed PVC pipe, for example, would permit sampling of termite activity at different soil levels. Possible field sites have been identified and design of an appropriate bait station for this field monitoring is a priority in the coming year.

I. Biological Investigations:

C. Biological Control

Living in a cryptic and protected habitat, subterranean termites appear to have few natural enemies. However, a number of pathogenic organisms do attack termite populations (cf., Edwards and Mill, 1986). One of these, a nematode (roundworm) parasite of many insects, Neoaplectana carpocapsae, is currently produced and marketed for subterranean termite control. Certainly, this nematode is capable of killing termites (Georgis et al., 1982), but its efficacy under field conditions is still a matter of debate (Mix, 1986).

Part of the problem with the field efficacy of this nematode parasite probably lies in the application technology. Currently, N. carpocapsae is mixed in an aqueous solution and injected into the soil and foundation wall voids in a manner identical to that employed with chemical termiticides. Delivery of the parasite in a more precise fashion to its insect host should enhance nematode survival and increase infection rates. We have available to us several different strains of N. carpocapsae (M. Hubbes, pers. commun.), as well as other nematode species reported to infect subterranean termites (G.O. Poinar, Jr., pers. commun.). We intend to evaluate the use of these parasites in the behavioural control techniques discussed above. It is possible that nematodes could be incorporated into baits, or applied to termite nests in a fashion similar to that suggested for insecticidal dusts. Limited soil treatment with nematodes in solution will also be investigated in the integrated approach to termite control described below under the heading "**Multi-tactic Control.**"

Fungi pathogenic to subterranean termites are another promising tool in the behavioural approach to control. Their potential for transfer throughout the colony (Kramm et al., 1982) mandates evaluation in our project as possible bait-block control agents. In particular, the fungus Metarhizium anisopliae has performed well in preliminary tests (Haenel and Watson, 1983; Kramm and West, 1982; Preston et al., 1982). We intend to isolate and culture fungi found in association with R. flavipes in Ontario in order to identify other potential pathogens, as well as possible sources of attractant compounds.

I. Biological Investigations:

D. Multi-tactic Control

The unifying theme of this research project is multi-tactic control. This is true integrated urban pest management: the thoughtful integration of behavioural, biological, physical, chemical, and sociological methods to formulate a prescription for the control of subterranean termites in Ontario.

This prescription for control will evolve from laboratory (and subsequent field) evaluations of termite feeding and mortality in bioassays exposing colony groups simultaneously to combinations of behavioural, environmental, biological, and chemical techniques. The synergistic or augmentative blending of multiple techniques is recognized as a means of achieving more rapid and lasting control of pest populations, and of slowing or preventing the development of genetic resistance to the control methods in those populations (National Research Council, 1969).

These investigations will be based upon the results obtained in the behavioural, environmental, and biological studies described previously. In addition, treatment of limited areas of soil with organophosphate and pyrethroid insecticides (cf., Mauldin et al., 1987), and alternative food sources impregnated with wood preservatives will be incorporated into multiple factor assays. Many new wood products and new preservative treatments are currently under development in North America, and we expect to have the opportunity to evaluate some of the more promising materials in the five-year course of Phase I of the project.

Accordingly, we have initiated contact with wood scientists working in this area of research.

II. Information Transfer and Exchange:

A. Research

Although the emphasis of the project is on technical aspects of subterranean termite biology and control, biological research does not exist in a social vacuum. The successful implementation of an innovative urban pest management program depends upon effective transfer of information and technology to practitioners, effective use of that technology, acceptance by the public, and a mechanism for feedback between the public, practitioners, and researchers (Frankie et al., 1986). Development of an integrated termite control program therefore entails extension and educational responsibilities.

Urban southern Ontario is a cultural mosaic. To adequately address through research the concerns of the diverse urban public with respect to pest control and pesticide usage, we must understand their perspective. Likewise, we must ensure that educational efforts are providing information actually needed by the public, in an appropriate format, and through appropriate information channels (Frankie et al., 1986). Carefully designed surveys are effective tools for obtaining this essential information (Frankie et al., 1982), and for providing ongoing feedback on pest management (Lambur et al., 1982) and educational efforts (Frankie et al., 1987).

This year, a pilot survey of public attitudes, information, and information sources on termite control was conducted in several urban areas. Experience and information gained in this pilot study will serve to design additional and more thorough surveys in the next four years. Results will be applied to design and modify research and educational projects, and should be of value as well to those providing public information in municipal, provincial and federal governments.

II. Information Transfer and Exchange:

B. Implementation

The project will not only communicate research results, but should serve more generally as an information resource. Thus, we will continue to develop training courses and informational presentations for building inspectors, and plan to develop presentations for other specialized groups (e.g., realtors, contractors, etc.) and segments of the public at large. These programs, and consultations on specific problems, should be partially supported by user fees.

Research progress will be monitored by the Advisory

Committee (Appendix I), and reported in periodic meetings. The project fiscal year is January-December, and an annual progress report will be distributed to the sponsors each January. Due to the issuance of this preliminary report, the 1987 annual report will essentially consist of a brief financial statement. Research results will also be reported to the Canadian news media, in scientific journals, and at technical and professional conferences.

Budget

		1988 Year 2	1989 Year 3	1990 Year 4	1991 Year 5
1.	Salaries				
	Project Director	$ 53,813	$ 56,504	$ 59,329	$ 62,295
	19% benefits	10,224	10,736	11,273	11,836
	Laboratory Technician 3	25,000	26,250	27,563	28,941
	19% benefits	4,750	4,988	5,237	5,499
	Postdoctoral Fellows (1,2,2,2)	22,000	46,200	48,510	50,936
	0% benefits	-	-	-	-
	Student Assistants (4 @ 50%)	33,280	34,944	36,691	38,526
	10% benefits	3,328	3,494	3,669	3,853
	Secretary 1 (25%)	5,000	5,250	5,513	5,789
	19% benefits	950	998	1,047	1,100
2.	Travel				
	Fieldwork	15,000	20,000	30,000	30,000
	Meetings, Consultations	5,000	8,000	8,000	8,000
3.	Equipment	110,000	30,000	15,000	15,000
4.	Supplies	30,000	35,000	40,000	40,000
5.	Computer Services	2,000	3,000	3,000	3,000
6.	Analytical Services	3,000	5,000	5,000	7,000
7.	Training and Advisory	5,000	15,000	15,000	15,000
8.	Other	5,000	8,000	8,000	10,000
9.	Contingency	17,500	12,400	12,400	12,800
10.	University Overhead				
	25% of 1, 2, 4, 6, 7, 8, 9	59,712	73,191	79,308	82,894
	0% of 3, 5	-	-	-	-
	TOTAL	$410,557	$398,955	$414,540	$432,469

Budget: Explanatory Remarks

1. Salaries:

The fiscal year for the project now coincides with the January - December calender year. The preliminary budget circulated in 1986 was based on the University fiscal year, with salary increases effective 1 July. Therefore, the annual salary figures presented here for the Project Director differ slightly, although the base salary and timing of annual increases are the same as originally projected.

In addition to the Project Director, the scope of the multi-disciplinary project outlined in this operating plan necessitates support of technical personnel in entomology, chemistry, pathology, and wood science. Students are needed as part-time research assistants during the academic year, and full-time in the summer for field work. With respect to the 1986 budget projections, this increase in technical personnel is partially compensated by removal of a laboratory technician position, and a reduction in secretarial time.

Although it is necessary to support technical assistance in the cooperating Faculty laboratories, the salaries of the four cooperating Faculty professors are contributed by the University.

Allowance for salary increases = 5% per annum.

2. Travel:

Funds for field work in Ontario include vehicle rental, accommodation and meals for the Director and project personnel. These expenses will increase as initial laboratory studies lead to field evaluations of promising materials and techniques.

Project personnel will attend professional meetings to exchange information and report research results. It is also necessary for the Director to consult with other researchers, both within Canada and internationally. A minimum of one annual visit to the U.S. Forest Service termite research facility in Gulfport, Mississippi, is anticipated, as are visits as necessary to other research centres.

3. Equipment:

This project entails establishing new research facilities. As indicated in the **Interim Financial Statement**, several items of laboratory equipment were purchased in Year 1 of the project. However, substantial equipment purchases are necessary in Year 2. These include: video camera and recorder, video digitizer and special effects generator, dedicated microcomputer for image analysis, image analysis software; an additional incubator; binocular microscope with camera adaptor; rotary evaporator; tissue macerator; top loading balance; stirring hotplate; portable digital thermometers and hygrometers, and portable data logger.

Although separatory and analytical equipment available in the wood chemistry laboratory will suffice initially, demands on this equipment will necessitate the purchase of a dedicated HPLC system with recorder and fraction collector in Year 3. It will also be necessary to continue to improve and maintain analytical, separatory, incubation, video, and computing equipment throughout the project.

4. Supplies:

Laboratory, office, and computer supplies. Laboratory supplies include: matrix and wood, paper, and pulp samples for termite rearing and bioassays; glassware; film; filter paper, weighing dishes, and other expendable materials; HPLC and GC columns; fungus and nematode culture media; and solvents.

5. Computer Services:

Campus mainframe computer facilities will be used for data management and evaluation, literature and database searches, and communication with other research centres.

6. Analytical Services:

Chemical analytical services (GC-MS, HPLC-MS, NMR) are available at the University of Toronto on a contract basis. Specialized services, such as chemical synthesis of pheromone analogues, must be arranged on a contract or fee-for-service basis with scientists at other research and educational institutions. Statistical consultations will also be necessary for efficient experimental design and appropriate data analysis.

7. Training and Advisory:

It is expected that the actual presentation of professional training programs and field consultations will be subsidized by user fees. However, funds are necessary to support the creation of professional training programs, informational presentations and materials for specific affected groups and for the general public, and ongoing evaluation of these efforts in **Information Transfer and Exchange.** We will also continue to acquire current reference and audio-visual materials, and subscriptions to scientific and professional journals.

8. Other

Postage, courier services, drafting, xerox, telephone, report preparation, and publishing costs.

9. Contingency

A modest amount (10% of direct costs other than salary) is allowed to accommodate unforseen expenses.

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APPENDIX I

DEVELOPMENT OF AN INTEGRATED CONTROL PROGRAM FOR THE EASTERN SUBTERRANEAN TERMITE

ADVISORY COMMITTEE MEMBERSHIP

Mr. D. M. Baxter (Chairman)
Executive Director
Economic Development Division
Municipality of Metropolitan Toronto

Mr. R. Bonner
Deputy Commissioner and Deputy Chief
 Building Official
Department of Buildings and Inspections
City of Toronto

Dr. J. R. Carrow
Dean
Faculty of Forestry
University of Toronto

Dr. J. Campbell
Research Consultant
Department of Public Health
Environmental Protection Office
City of Toronto

Mr. B. Delaney
President
Ontario Pest Control Association

Mr. M. Dunbar
Executive Director
Association of Municipalities of Ontario

Mr. B. Gray
Project Officer
Research Division
Canada Mortgage and Housing Corporation

Dr. J. F. Keffer
Vice-Provost
University of Toronto

Mr. E. N. Merkur
Vice-Chairman
Apartment Group
Urban Development Institute

Mr. R. E. Millward
Commissioner
Planning and Development Department
City of Toronto

Mr. M. Rendle
Commissioner of Planning and Development
Corporation of the Borough of East York

Mr. A. T. West, Jr.
Ontario Association of Architects

Mrs. I. Wile
Director
Hazardous Contaminants Coordination Branch
Ontario Ministry of the Environment

APPENDIX II

"Tiny Problems That Bug People"
The Toronto Star
28 February 1987

Metro Weather
Rain. High 2C.

THE SATURDAY STAR

February 28, 1987
$1.00
The Toronto Star Established 1892
January/87 Saturday paid circulation 795,117

Tiny problems that bug people

JACK MILLER
SCIENCE

IF we'd settled in the beginning for living in mud huts, or at least for building houses from local trees and not importing fancy furniture, maybe this wouldn't have happened. But it's hard to be sure. Even driftwood blowing across Lake Erie from Ohio might have brought *THEM* in.

'Them' are termites. We've had them in Ontario from the mid-1920s, when they were spotted near the west end of Lake Erie. Ever since, they've been spreading east, all the way to Hamilton, then to Toronto. Look at the map.

They're thick in the Beaches. They're strung out along the Queensway in Etobicoke. The stockyards in York are loaded with them. North York has only a few small spots so far but East York is heavy south and east of the parkway and in Leaside. Now they're showing up west of Bayview and north of Eglinton. In Scarborough, the most forward position so far in their eastward sweep, they're eating their way north from the bluffs, and along Kingston Road.

"We can only estimate the cost in dollars," said Robert Lott of Toronto's department of buildings and inspections, "but it's in the millions, yearly."

There are ways to deal with termites, but one of the big problems is getting people to watch for them and spot the problem before it's too late — like, before the kitchen floor disintegrates under their next step and deposits them in the cellar.

"This has nothing to do with how clean you keep your place," said Lott. "Termites are not like cockroaches — they don't eat grease or loose food *in* your house, they eat the house *itself*."

What they eat, specifically, is cellulose, the main ingredient of wood. They get inside a board or beam and chew the soft wood between the lines of the grain, and leave it hollow. From the outside, usually nothing shows.

It could be worse. We have only one kind of termite here — a type that lives underground. There are meaner ones, but ours are bad enough. They make nests deep underground outdoors and then build little tube-like passages up the sides of a house's foundation to get to the wood siding, or to a crack that will let them crawl in to the beams under the main floor.

Every day they crawl in through this tunnel, gorge on wood, make that wood more hollow and weaker, then crawl back to their underground nest because they need the moisture there. They'll dry up if the humidity in their environment drops much below 95 per cent.

Usually those tunnels up the foundation walls tip people off that they've arrived, and the fight is on. Our main tactic so far is to inject poison into the ground around the house. We use three main ones — Chlordane, Aldrin and Dieldrin. They bind with the soil to create an underground chemical "moat" around the building that lasts up to 20 years. The termites can't get through it to follow their tunnels into the house for dinner. Those inside can't get through it to go back to the moist underground nest, so they stay in the house and die of dehydration after a few days.

Ontario pays out $500,000 a year in grants to help finance this sort of fight, says Geoff Cutten of the provincial environment ministry. (Call your city building department if you need this kind of help). Toronto is getting $300,000 of it — and that's the city alone, not all of Metro.

The standard tactics work pretty well to save a house, if you get at it before it's badly weakened. But it does nothing to find and kill the main populations in those outdoor underground nests, which can be more than a metre long. So we have not found a way to stop the sweep to the east.

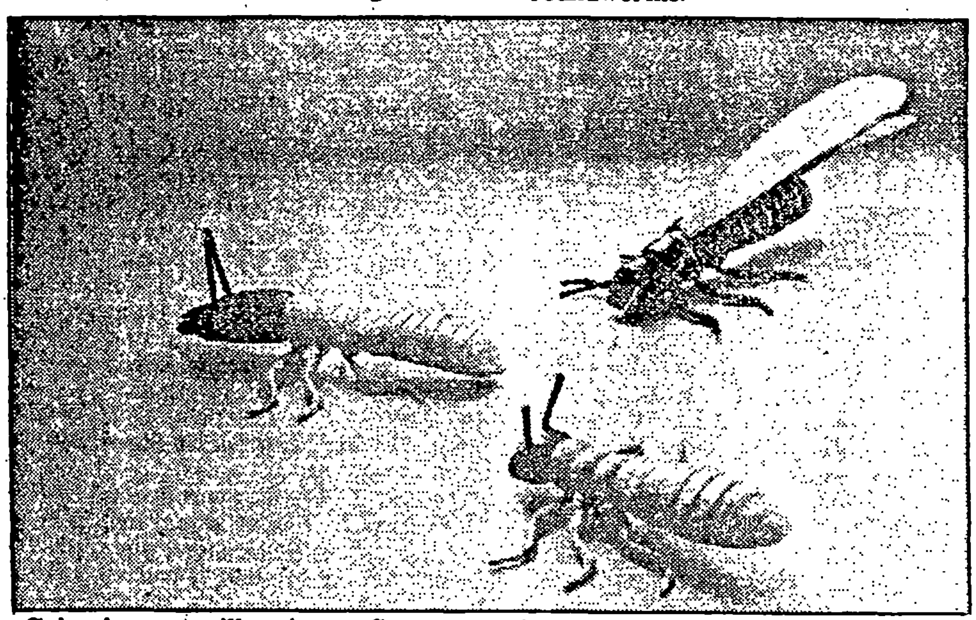
Now we're beefing up our scientific muscles for this fight. The University of Toronto's forestry department will be the base for a new termite research project, with about $750,000 in five-year funding from an assortment of concerned donors ($200,000 from the city, $150,000 from Canada Mortgage and Housing Corp., among others).

The main weapon in the new project, so far, is Ken Grace, a PhD-level termite expert from Berkeley, California, who has just joined the faculty. His job will be to ferret out the social secrets of the local breed, and then to figure how to use their normal urges to lead them astray.

They are, he points out, blind. They lead each other around by the smells they leave behind them. They groom each other by doing a lot of licking. They feed each other in ways which presumably are very social by termite standards, although if people did it, they might be up on morals charges.

The job is just starting, but mainly it will be to look for alternatives to standard poison to win this fight. "Their chemicals are all a mystery to us, and we're just figuring out what their means of communication is," Grace said.

If we can get that down pat, we may find ways to give them all the wrong signals, to upset their lives more than they can bear. And if that doesn't work, we may even find a way to kill them by infesting them with — are you ready? — roundworms.



Scientists are still trying to figure out what makes termites tick

APPENDIX III

"Gnawing Problem: Termites Work Faster
Than Prevention Methods"
The Globe and Mail
20 July 1987

GNAWING PROBLEM

Termites work faster than prevention methods

BY HENRY HESS
The Globe and Mail

It may be home to you, but to *Reticulitermes flavipes*, it is just lunch.

If you live in Metro Toronto — or in one of several dozen other communities in Southern Ontario or in British Columbia — *R. flavipes*, better known as the eastern subterranean termite, or one of its cousins may already be dining at your expense.

Unless you go looking for them, you probably will never know they are there until it is too late. Termites are as discreet as they are voracious, working under cover and in the dark, so that often the first sign of their presence is the ceiling falling on your head or your foot going through the floor.

Officially, slightly more than 20 per cent of the houses in Toronto are in areas infested by termites.

But that probably understates the threat. Expert witnesses at a recent civil trial testified that it is only a matter of time before termites eat their way into every house in Metro that has not been treated against them.

Structural damage to buildings in Toronto alone is already estimated at considerably more than $1-million a year.

Reginald Hummel, a lawyer who went to court in December on behalf of a Scarborough house buyer who found his house to be "crawling with termites," described that case as the first shot in a continuing battle to decide whether sellers are obliged to warn buyers about termite infestation.

In that case, a District Court judge ruled that the buyer had to prove the seller knew about the termites, which Mr. Hummel calls an almost impossible requirement. A similar case is still before the courts.

"The basic law is *caveat emptor*: let the buyer beware," said Mr. Hummel, whose own home has been treated for the bugs.

He now advises clients to insist a house be checked by a qualified termite inspector before they buy. However, he said, the real estate market has been so hot that most people have signed a sale agreement before they see a lawyer.

A termite clause, similar to the one that requires urea-formaldehyde foam insulation, to be reported should be on the standard real estate sales form, he said.

But the Toronto Real Estate Board rejects the idea.

"You're expecting too much of the real estate agent," argued Edward Bou, a board spokesman. "If the purchaser exercises a little care, he can find (termite infestation) fairly easily."

People on the front lines of the termite battle disagree. "Usually, they will have done extensive damage before you even know they're there," said David Smusiak of Pestco, a Toronto pest-control company.

ERIK CHRISTENSEN/The Globe and Mail

Dr. Kenneth Grace examines a jar containing termite specimens: grains of rice with legs.

"Houses are being bought and sold and the new owner is being stuck with termites," said Richard Murphy, a former president of the Ontario Pest Control Association whose company, Aetna Pest Control Ltd., treats 600 to 700 houses a year in Metro.

Mr. Murphy said he knows one buyer who found out he had termites only when he decided to replace the living room carpet. "He took the carpets up and there was no floor in the bungalow."

Mr. Murphy said he has seen structural damage run as high as $40,000.

One woman, who asked not to be identified, said her husband suspected termite damage when they bought their house in Riverdale, but the agent assured them it was only dry rot and the seller refused to allow an inspection before the sale.

Since then, their two-story house has been jacked up to replace floor joists weakened by termites.

Lawyer lobbies hard for inspection clause

Termites first showed up in Toronto 50 years ago in a building near the docks on Toronto Bay. Since then, they have been eating their way across the city. Hardest-hit have been the Riverdale and Upper Beaches areas, whose older homes are vulnerable to attack. From there, the insects have spread into about half of East York and one-third of Scarborough.

Recently, they have been showing up in increasing numbers in Kensington Market, Cabbagetown and the area around Avenue Road and St. Clair Avenue.

Termites travel readily. They turned up in Newmarket after a truckload of soil from the Beaches was dumped there, Mr. Smusiak said.

Colonies have also been found in 28 municipalities across Ontario, including Windsor, Hamilton, Kincardine and Guelph.

A close cousin, the western subterranean termite, lives in southern British Columbia. So far, neither species has turned up in any numbers elsewhere in Canada, but experts say there is no reason to expect they won't.

A full-grown subterranean termite looks like a grain of rice with legs and can do a vast amount of damage. Living in colonies of up to half-a-million, working 24 hours a day, [illegible] the house out from under you.

"No buildings are immune," said Dr. Kenneth Grace, head of the newly established termite research project at the University of Toronto. "You'll find them on the sixth or seventh floor of a concrete and steel building, feeding on the bookcases."

"Termites can go through an immense variety of materials," he said. They will chew through plastic, including the insulation on buried power lines, and while they cannot tackle solid concrete, they are capable of enlarging tiny cracks. Since they work on wood from the inside, leaving the shell intact, the damage can easily go unnoticed.

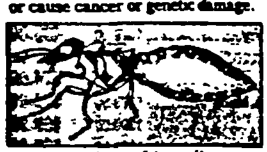
The five-year, $1.5-million project is aimed at finding ways to control termites that will be safer than the traditional method of injecting highly toxic chemicals into the soil around and under a house. It was established at the urging of the City of Toronto, with provincial and municipal financing.

A major problem facing termite-fighters is that their most effective weapons are potentially dangerous chemicals.

The pesticides chlordane, aldrin or dieldrin, pumped into the soil around a house, set up an effective and long-lasting barrier to termites.

But tests have found these chemicals can cause cancer, genetic abnormalities and learning impairment in laboratory animals. Chlordane has been banned in parts of the United States and production of all three chemicals has virtually halted.

In their place is a newer pesticide, chlorpyrifos, marketed as Dursban TC, which is just as lethal but does not stay in the soil as long or cause cancer or genetic damage.



Drawing of termite.

Another new poison that is less toxic to humans, permethrin, has been licenced in the United States and is expected to be approved in Canada within a year.

But exterminators complain the new pesticides are more expensive and do not work as well.

Geoffrey Cotten, of the hazardous contaminants branch at the Ontario Ministry of the Environment, said Canadian tests indicate that chlordane can be safe and effective if properly applied. However, James Flaherty of the Toronto Department of Health said he has seen too many cases in which the pesticide was not used properly.

There have been some experiments in Toronto using nematodes, microscopic roundworms carrying bacteria that attack a termite from inside, but Dr. Grace said it is too early to tell whether this will work.

The final answer, he said, probably lies in tinkering with the hormones that control the bug's development and behavior.

Scientists know remarkably little about what makes termites tick, he said.

They do know that colonies are divided into workers, soldiers and reproducers, and that most of the insects in a colony are workers.

But nobody knows why two identical larvae can develop into different adult forms — or how a worker can transform itself into an egg-layer if separated from the colony.

Many chemicals are carcinogens

Only about 4 per cent of homes treated for termites have been reinfested, but when the insects are blocked from one house they just go on to another.

Since 1963, building inspectors in Toronto have had the authority to order soil treatment of all infested properties, as well as neighboring buildings, and since 1984 the city has required advance treatment of soil for any new construction using wood.

Homeowners can apply for provincial grants of up to $2,000 and a city grant of $125 to help with the cost of fighting the infestation, but approval can take two or three months.

Last year, Toronto spent nearly $80,000 and the province spends $500,000 annually on termite control. But officials calculated that at the current rate of treatment, it would take 50 years just to treat all the houses in the areas already known to be infested.

And scientists warn that an even hungrier breed of bug is heading this way.

A Formosan termite that lives in even bigger colonies, eats twice as much and loves to travel, showed up in Florida several years ago and at last report had reached South Carolina and Texas.

"They could be introduced (to Canada) easily," Dr. Grace said, "because they do move around by [illegible]

APPENDIX IV Document No: IRG/WP/1333

THE INTERNATIONAL RESEARCH GROUP ON WOOD PRESERVATION

Working Group 1b Biological Problems (Fauna)

Termites in Eastern Canada: A Brief Review and Assessment

by

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Termites in Eastern Canada: A Brief Review and Assessment

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ABSTRACT

The distribution of termites in Canada is reviewed, with particular emphasis on the eastern subterranean termite *Reticulitermes flavipes* (Kollar) in Ontario province. Municipal and provincial termite control programs are discussed and current treatment practices are described. Previous research on *R. flavipes* in Ontario is briefly reviewed, with reference to a number of unpublished reports and publications of limited distribution.

Keywords: *Reticulitermes flavipes*, subterranean termites, Rhinotermitidae, termite distribution, termite control.

TERMITE DISTRIBUTION

Only four species of termites are known to occur in Canada and their occurence is, in general, limited to the southern portions of two provinces, British Columbia and Ontario. According to Blackall (1981), isolated instances have also been reported in southern Quebec and the Maritimes, undoubtedly due to transport of infested wood. On the Pacific coast, the western subterranean termite *Reticulitermes hesperus* Banks (Rhinotermitidae) occurs throughout southern British Columbia, as do the two rotten wood termites *Zootermopsis angusticollis* (Hagen) and *Z. nevadensis* (Hagen) (Termopsidae). In the eastern province of Ontario, the eastern subterranean termite *Reticulitermes flavipes* (Kollar) was apparently first reported in the southernmost portion of the province at Point Pelee (Essex County) in 1929 (Kirby 1965, 1967). Whether it is indigenous to this area is a matter of debate (cf. Cooper and Morris 1981; Husby 1980), although some suspect that *R. flavipes* was introduced to Point Pelee in lumber brought in from the United States to construct vacation cottages (G.M. Cutten, personal communication). In other portions of Ontario, *R. flavipes* has only been found in the vicinity of human habitations, although not necessarily within those habitations.

Following its discovery at Point Pelee, R. flavipes was
58 reported damaging a building on the Toronto lakefront in 1938, reportedly as the result of an introduction from the United States around 1935 (Urquhart 1953). The growth of this and subsequent infestations in the greater metropolitan Toronto area has since been the major cause of concern in Ontario. Termites have now been reported in 13% of the city blocks in Toronto (Jafri 1987). To date, subterranean termite infestations have been reported in 28 Ontario municipalities (Cutten 1987). The northernmost known site of infestation is Kincardine (Bruce County), where R. flavipes was first collected in 1954 from a rubbish pile near the railway station (Kirby 1967).

MUNICIPAL AND PROVINCIAL PROGRAMS

A unique aspect of termite control in Ontario is the degree of involvement of provincial and municipal governments in inspection and control, rather than simply in regulation of the pest control industry. In 1962, the City of Toronto appointed a full-time termite inspector (Jafri 1983). Enabling legislation enacted by the provincial government in 1963 empowered municipalities to pass by-laws providing for both preventive and remedial termite control measures, and financial assistance to property owners. As enacted by Toronto (in 1963, replaced in 1973 and revised in 1984) and other affected municipalities, these by-laws give municipal building inspectors authority to require soil treatment of infested properties and elimination of earth-to-wood contacts. Some by-laws (e.g., Toronto) also provide authority to order soil treatment of adjacent properties as a preventive measure. In 1984, the Toronto by-law was revised to require pre-treatment of soil for new construction where wood structural members are used. These by-laws also apply to other wood destroying insects, such as carpenter ants which are a significant problem in some areas (e.g., the northern section of Toronto).

Although several private pest control companies are willing to inspect properties for termite infestation, such inspections are usually performed by a municipal building inspector - either at the request of a resident, in the course of surveying a selected area of the city, or in conjunction with other building inspection duties. If a private pest inspector recognizes termite infestation, a municipal inspector would then also have to visit the site in order for the property owner to take advantage of financial assistance programs. This arrangement (inspection by a public official) avoids the potential for conflict of interest and unethical behaviour inherent in a private termite inspection industry, but also begins to strain the resources of municipal personnel as public awareness and incidences of infestation increase. Unless these resources can be increased in proportion to the extent of the problem, more delegation of inspection responsibilities to private inspectors will be necessary.

Where termite infestation is noted, the property owner is instructed (mandated) by the city to contact any of several private pest control companies registered with the city to perform termite control, and to eliminate any contacts between wood members and the soil. The municipal inspectors also assist in completing the forms necessary to recover a portion of the costs of these control measures from the municipal and provincial grant programs.

Currently, the grant program administered by the City of Toronto will reimburse property owners 25% of the cost of soil treatment, either with chemicals or nematodes, to a maximum of CDN $125 (Jafri 1987). Other municipalities offer similar grants. In addition, provincial grants administered by the Ontario Ministry of the Environment will cover 60% of the combined cost of chemical soil treatment and wood-soil separation, to a maximum of CDN $2,000. The province will also pay 60% of the cost of soil pre-treatment for new construction, to CDN $1,000. Other grants for home repair are available to low-income property owners. The Ministry of the Environment also monitors termite activity in Ontario through annual inspection surveys of selected areas.

Grants for termite control cost the Ontario provincial government CDN $500,000 annually, while the City of Toronto spent CDN $46,822 for soil treatment grants in 1986 (Jafri 1987). Since these grants cover only a portion of treatment costs and do not include costs for most structural repairs, actual losses due to termites certainly exceed this amount.

CURRENT CONTROL PRACTICES

As indicated by the requirements of the municipal by-laws and the provincial grant program, wood-soil separation is recognized in Ontario as essential to subterranean termite control. The Toronto by-law requires that such structural problems be corrected before chemical treatments are performed, and the province partially subsidizes the cost of eliminating wood-soil contacts.

Soil treatments with termiticides are extremely thorough: if evidence of termite infestation is found anywhere on the property, then sub-slab and soil injection is used to treat both sides of the entire peripheral foundation wall and any intermediate bearing walls and columns. Brick, hollow block, and rubble foundations are all common in eastern Canada, and wall voids are drilled and injected with termiticide. R. flavipes frequently attacks living trees in Toronto, and termiticide is injected into the soil around infested trees to contain the infestation.

Aldrin, chlordane, and chlopyrifos are all currently registered for soil treatment in Ontario. Of these, only chlopyrifos is actually marketed in Canada at this time, but aldrin and chlordane remain the most common termiticides due to existing stock. Registration of permethrin is in process, but is likely to take at least another year (G.M. Cutten, personal communication). Nematodes are available, but have been used to treat only a few properties. Nematode applications can be subsidized under the Toronto grant program, but not under the provincial program.

Current soil treatment methods faithfully implement the "barrier" approach to termite control. However, they also place a large chemical load on the environment. As in the eastern United States, public health concerns have been raised about the cyclodienes, leading the Toronto Department of Public Health to propose a ban on their use. With chlorpyrifos available as an alternative, pressure for such a ban is likely to increase, as in New York State.

TERMITE RESEARCH IN ONTARIO

R. flavipes is widely distributed in eastern and southeastern North America, and examinations of this species at the northernmost limits of that range have euristic appeal. However, research in Ontario has emphasized mapping the distribution of the species and evaluating the success of control efforts. Kirby (1967) reports on the use of large numbers of spruce bait stakes to survey termite activity in Toronto and southern Ontario in 1948, 1952, and 1962. Baits decayed by Gloeophylum trabeum were used by Esenther and Gray (1968), and this led to the successful demonstration in Ontario of the efficacy of the bait-block method of control by Ostaff and Gray (1975). The Ministry of the Environment continues to use bait stakes to a limited extent in their surveys, but the emphasis has shifted to more intensive inspection of buildings, fences, and trees in selected areas.

Much of the information on subterranean termites in Ontario is available only in government publications of limited distribution and unpublished research reports. In the first category are a well-illustrated consumer pamphlet (Anonymous, undated) and a very complete manual on termite control (Cutten 1987) distributed by the Ontario Ministry of the Environment, and reports issued by several municipal governments. The City of Toronto Planning and Development Department issued a comprehensive study of termite control in Toronto in 1983 (Jafri 1983) and has continued to issue detailed annual reports on the subject (Jafri 1987).[1]

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[1]Available upon request from Mr. Anwar Jafri, Planning and Development Department, City of Toronto, E 19th, City Hall, Toronto, Ontario, Canada M5H 2N2.

Cooper (1987) reports briefly on a study of the occurence of *R. flavipes* in trees in Toronto conducted in 1980 (Cooper 1981). In unpublished reports, Keefer (1979) and Cooper and Morris 6 (1981) provided historical reviews and evaluations of the termite problem in the province. Husby (1980) studied *R. flavipes* colony composition, reproduction, and seasonal cycles.

From late 1982 through April 1984, the City of Toronto employed Dr. R.V. Carr as a consulting entomologist. Among Carr's recommendations was the suggestion that facilities for research on termite biology and control be established in the Toronto area (Carr 1987; Jafri 1987). This led the City of Toronto Department of Buildings and Inspections to enlist the cooperation of the Faculty of Forestry at the University of Toronto in an effort to establish a Chair of Urban Entomology, with termite research the principal focus. This unique effort was modified to the creation of an Urban Entomology Research Project within the Faculty of Forestry, initially for a period of five years. Through the persistent efforts of Faculty and City representatives, support for the project was derived from a broad base of municipal, provincial, national, and private sources, and a Director was appointed in January 1987. Research specifics are now in the planning stages since the greater portion of the first year of the project is concerned with problem analysis. However, the general focus of this program is on characterization of some of the biological, environmental, and sociological variables impinging on *R. flavipes* control in Ontario, and on long-term reduction of chemical usage through the development of alternatives and adjuncts to current methods of termite detection and control in eastern Canada.

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APPENDIX V

NOTE

ASSOCIATION OF THE EASTERN SUBTERRANEAN TERMITE, *RETICULITERMES FLAVIPES* (KOLLAR) (ISOPTERA: RHINOTERMITIDAE), WITH LIVING TREES IN CANADA

Key Words: Eastern subterranean termite, *Reticulitermes flavipes*, Rhinotermitidae, termite foraging behavior, urban tree pests.

J. Entomol. Sci. 22(4): 353-354 (October 1987)

Subterranean termites in the genus *Reticulitermes* are rarely reported in living trees. When such associations are reported, the infestation generally originates and spreads internally in the plant. That is, termites move from the soil into the roots and heartwood, with little evidence of infestation visible until extreme damage has occurred (cf. Banks and Snyder. 1920. U. S. Nat. Mus. Bull. 108; Harris. 1966. Forest Abstr. 27: 173-78; Marlatt. 1908. USDA Bur. Entomol. Circ. No. 50). However, in southern Ontario, Canada, at the northernmost limits of its distribution, *Reticulitermes flavipes* (Kollar) initiates above-ground activity in living trees by constructing shelter tubes from the soil up the exterior surface of the bark, and constructing galleries between the inner and outer bark. This note is intended to document this behavior, and to stimulate consideration of the ecological rationale for this limited behavior over the wide geographic range of *R. flavipes*.

In 1980, approximately 17,800 street and park trees throughout Metropolitan Toronto were inspected for subterranean termite activity (Cooper. 1987. Proc. Can. Wood Preserv. Assoc. [1984] 5: 60-61). Of these, 4% had *Reticulitermes* shelter tubing on the bark. Termites were present on 19.3% of the horse chestnut, *Aesculus hippocastanum*, trees inspected, 17.8% of the silver maples, *Acer saccharinum*, and 13.7% of the sugar maples, *Acer saccharum*. These are the most frequently planted tree species in Toronto. No tubing was found on sycamore, *Platanus occidentalis*, spruce, *Picea* sp., or pine, *Pinus* sp. Although tubes did not always lead to decaying wounds, as observed by Esenther et al. (1961. Science 134: 50), such wounds were present on 54% of the termite-infested trees. However, tubing was also noted on trees with healed wounds (42% of those infested) and on an occasional tree with no apparent wounding.

Much of the tubing seen on trees may represent initial and unsuccessful explorations by *R. flavipes*. Although the bark is slightly scarred beneath exterior termite tubes, we have not observed direct penetration of sound phloem by *R. flavipes*, as reported by Rhoads, Meyer, and Jeffries (1979. J. Arboriculture 5: 162) on park trees in Philadelphia, PA.

In the 1980 study, a Norway maple, *A. platanoides*, (DBH 35 cm, height 15 m) with a dying crown and termite tubing extending to the top was dissected. Mixed castes of termites were found in the tubes, immediately under the bark in dead areas of the tree, and in dead branch stubs. Since urban shade trees are subject to numerous stresses and some degree of physical damage is not uncommon, exploration by *R. flavipes* up the exterior and interior bark surfaces probably leads to opportunistic feeding on dead areas. It is not known whether termite colonization of these dead areas and traffic between the inner and outer bark contributes to tree mortality.

When inspecting buildings in Toronto for termite infestation, it is common practice among municipal building inspectors and pest control operators to also examine the adjacent trees. *Reticulitermes flavipes* is considered an introduced pest in Ontario (Urquhart. 1953. Can. Entomol. 85: 292-93), with a spotty distribution, and any occurrence in proximity to buildings is cause for concern. Infested trees are treated by pressure injection (rodding) of termiticide in the surrounding soil. This may prevent the colony from traveling through the treated soil to adjacent buildings, but eradication is unlikely. Spraying the trunk with termiticide prevents reconstruction of exterior tubing for at least one year (Cooper. loc. cit.), but is illegal under current labeling. Lack of proper disposal of infested wood after tree trimming or removal is also a serious concern to regulatory officials in Ontario, since movement of infested wood and (possibly) top soil are considered the major means of long-distance dispersal of *R. flavipes* in the province.

Investigations of the foraging and overwintering behavior of northern *R. flavipes* populations, and of the apparent preference for certain tree species, are necessary to develop practical recommendations for arboriculture and termite control in Ontario. Comparative studies with termite populations from other regions may help to explain why external shelter tubing on living trees is not commonly found among southern (R. Scheffrahn, personal communication) or western (Grace, unpublished observation) *Reticulitermes* populations.

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THE CHALLENGE OF WOOD DESTROYING INSECTS

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In 1984, R. V. Carr addressed the Canadian Wood Preservation Association on the subterranean termite problem in Toronto (Carr, 1987). In that address, he discussed his employment by the City of Toronto as a consulting entomologist, and the implementation by the city of the recommendations arising from that association. One of these recommendations was that the Department of Buildings and Inspections of the City of Toronto work with representatives of academia, industry, and the provincial government to develop a research program in urban entomology within the Faculty of Forestry at the University of Toronto. Although it has taken several years of organizational and lobbying efforts, this research program is now underway.

The primary goal of the urban entomology research project is the development of an integrated control program for the eastern subterranean termite, Reticulitermes flavipes (Kollar), in the urban environment. Obviously, such an ambitious goal necessitates basic, as well as applied, research efforts. To develop appropriate methods of control, one must first understand the behaviour and biology of the insect in the habitat of concern. Additionally, it is our intent that the research program expand with time to include other wood destroying insects, and the many other arthropods associated with man in the urban environment. In defining research priorities and directions, we wish to encourage input from all concerned parties, certainly including the membership of professional associations such as the CWPA which are concerned with the preservation of wood in service.

In this paper, I hope to provide an overview of wood destroying insects in North America, and a personal perspective on current research efforts with respect to their control. Although many of these insects may not be found in Ontario, or in other Canadian regions, the possibility exists of their introduction. Exterior environmental conditions may vary drastically from one area to another, but conditions within human habitations are frequently quite uniform. Once insects are introduced to a new geographic region, they can survive in our man-made environments, and frequently exhibit an unsuspected ability to adapt to different exterior conditions as well. Introduction may occur through commerce, or by casual movement of infested wooden objects, lumber, or even firewood. The eastern subterranean termite, for example, is thought to have been introduced to Toronto in infested material (Grace, 1987; Urquhart, 1953). Thus, an understanding of the wood destroying insects found in other regions of North America may help us evaluate their potential for introduction to Canada, and more rapidly and knowledgeably cope with such introductions when they occur.

Termites

Termites are certainly the most economically important wood boring insects in North America. The annual cost of termite control in the United States has been estimated at (US)$753,400,000 (Mauldin, 1986) to $1,020,000,000 (Edwards and Mill, 1986). Although only 69-80 of the more than 2,200 species of termites occurring worldwide infest buildings (Ebeling, 1975; Edwards and Mill, 1986), the costs of their control have been estimated at nearly (US)$2000 million (Edwards and Mill, 1986).

From an entomologist's point of view, termites are related to cockroaches and grouped into seven families: Mastotermitidae, Kalotermitidae (drywood termites), Termopsidae (rottenwood or dampwood termites), Hodotermitidae, Rhinotermitidae (subterranean termites), Serritermitidae, and Termitidae. The family Termopsidae is sometimes considered to be a subfamily (Termopsinae) within the family Hodotermitidae, particularly in American classifications. Only three of these seven families - Kalotermitidae, Termopsidae, and Rhinotermitidae - contain species of importance as pests in North America. In Canada, the eastern subterranean termite, *R. flavipes* (Rhinotermitidae), is found only in Ontario and two other species, *Reticulitermes hesperus* (Rhinotermitidae) and *Zootermopsis angusticolis* (and possibly *Z. nevadensis*) (Termopsidae) are present in British Columbia (Snyder, 1949).

Like ants and bees, termites are social insects. As such, they are characterized by three traits: (1) individuals of the same species cooperate in caring for the young; (2) there is a reproductive division of labour within the colony; and (3) at least two generations overlap in the nest, so that offspring assist their parents (Wilson, 1971). The specialized body forms, or "castes," found in termite colonies are a reflection of this division of labour.

The eastern subterranean termite in Ontario and a second subterranean termite, the Formosan subterranean termite (*Coptotermes formosanus*), in the southeastern United States provide examples of introduced pests thriving in their new environments. The Formosan subterranean termite was apparently introduced to North America through maritime commerce, and is now found as far north as Charleston, South Carolina, and as far west as Texas (Su and Scheffrahn, 1986). Unlike *Reticulitermes* species, *C. formosanus* readily nests above ground in buildings with no connection to the soil (Su and Scheffrahn, 1986). *Coptotermes formosanus* colonies are also larger and more mobile than those of *Reticulitermes*.

The author has observed C. formosanus chewing through plastic lids on containers in the laboratory.

In Ontaɪio, R. flavipes was collected at Point Pelee in 1929 (Kirby, 1967), and is thought to have been introduced to the Toronto lakefront from the United States between 1935 and 1938 (Urquhart, 1953). Movement by man of infested materials has spread the infestation as far north as Kincardine. Currently, 28 municipalities in Ontario have reported subterranean termite activity (Cutten, 1987).

Wood Boring Beetles

Termites are not the only insects feeding on seasoned wood. Three families of beetles also commonly infest seasoned structural timbers and wooden objects: Lyctidae (true powderpost beetles), Bostrichidae (false powderpost beetles), and Anobiidae (deathwatch or furniture beetles). These are not social insects, but continued reinfestation of timbers literally reduces the wood to powder. The old house borer, Hylotrupes bajulus (family Cerambicidae - the longhorned beetles or roundheaded borers), is a serious pest in Europe which now occurs along the Atlantic coast of the United States (Robinson, 1986).

Beetles that normally bore into green wood may also cause problems when that wood is used in building construction. Although these insects will not reinfest the dry timber after emerging from it, their relatively long life cycles may allow the immature beetles to do substantial damage to the wood before emerging through finished surfaces or wall coverings as adults. Not infrequently, beetles in the family Cerambicidae, such as the 6 cm long Ergates spiculatus, cause this type of damage (Ebeling, 1975).

Occasionally, beetles infesting stored food products and not normally considered to be wood borers will cause serious damage. These occasional invaders of wood include larder and hide beetles (family Dermestidae) and spider beetles (family Ptinidae) (Ebeling, 1975; Grace, 1985b). It is unlikely that these beetles derive any nutrition from wood, and damage is usually reported only with heavy beetle infestations in granaries, grain elevators, mills, and packing plants. However, under some conditions damage can also occur in residential conditions, where it could be mistaken for that of the more common wood boring beetles and unnecessary or improper treatments applied (Grace, 1985a, 1985b).

Carpenter Ants and Bees

Neither carpenter ants (Hymenoptera: Formicidae, genus Camponotus) nor carpenter bees (Hymenoptera: Anthophoridae, genus Xylocopa) feed on wood. That is, they do not digest or derive nutrition from it. However, both excavate cavities in wood and enlarge existing cavities for nesting purposes.

Carpenter ants are most common in wooded, or recently wooded, areas. In Toronto, carpenter ant infestation is a serious problem in the northern portion of the city, but the damage is less significant and the costs of control are less than those associated with termite infestation (Jafri, 1983; Jafri, 1986).

Current Pest Control Technology

Current techniques for controlling wood destroying insects are thoroughly reviewed by Moore (1986). Although mechanical exclusion of insects from buildings is important (e.g., insuring that no timbers are in contact with the soil to exclude termites, and cutting back vegetation and sealing any cracks in the exterior walls to exclude ants), remedial control is most often accomplished with pesticides and fumigants. Although insects cannot survive on wood treated with preservatives, the thoroughness of the treatment, degree of penetration of the timber, and leaching of the preservative with time are important considerations. The degree of subterranean termite resistance imparted to the rest of the structure by the presence of a preserved wood (all-weather) foundation system is one area of current interest (Bryant, 1983). In this case, termite resistance would depend more upon insect repellency than upon the toxicity of the preservative.

In Ontario, subterranean termites are controlled by soil treatment with one of several cyclodiene chlorinated hydrocarbons (aldrin, chlordane, dieldrin) or an organophosphate (chlorpyrifos). A synthetic pyrethroid (permethrin) is available for use in the United States, and Canadian registration is anticipated. A carbamate insecticide (bendiocarb) may also be available for this use in the near future.

Wood boring beetles, and drywood termites, are usually controlled by fumigation with methyl bromide or sulfuryl floride (Vikane). Where carpenter ants and bees cannot be mechanically excluded from the structure, insecticide is applied to their nesting cavities.

However, many current methods of pest control are becoming less viable as a result of potential toxicological and environmental problems. In the United States, Massachussets and New York do not currently allow the use of cyclodienes for termite control (New York State Dept. of Environmental Conservation, 1986), and similar concerns have been raised by the Medical Officer of Health of the City of Toronto (Neighbourhoods Committee, 1986). The safety of fumigants has also generated public concern (Walter, 1985). Questioning of the toxicological and environmental safety of these materials has also brought about a sharp increase in the costs of liability insurance associated with their production and use. Thus, as the available materials are restricted, the costs of pest control increase, and these costs are ultimately borne by the consumer.

Still, we cannot abandon wood as a building material, as was attempted by a couple in southern California who built a steel house to avoid termite infestation (Ryon, 1985). Even in a steel house, a house built entirely of pressure treated wood, or a concrete and steel apartment building, there will still be cellulose materials susceptible to insect attack. Stored boxes, books, cabinets, furniture, and wooden art objects are all susceptible to infestation by termites or beetles. The author has encountered spider beetles (family Ptinidae) mining a kitchen cutting board (Grace, 1985a, 1985b). Moreover, the many wood frame structures already in existence must be protected. The continuing need for safe, efficacious means of pest control necessitates the development of entirely new techniques for controlling these insects, rather than simply exchanging toxicants.

New Research Directions

Researchers are currently studying a number of promising alternatives or adjuncts to current methods for controlling wood boring insects. Among these are: biological control with insect pathogens; modification of the insects' behaviour with chemicals similar to those used by the insects to communicate and to locate food; interference with the hormones regulating growth and development; attraction to toxic baits; and the use of repellents and feeding deterrents. Many of the new approaches discussed here are also reviewed in somewhat greater detail in a new book on termite control (Edwards and Mill, 1986), received by the author after the original delivery of this paper.

A roundworm parasite of insects, <u>Neoaplectana carpocapsae</u> (family Steinernematidae), is currently produced and marketed for subterranean termite control. Certainly, this nematode is capable of killing termites (Georgis et al., 1982), but its efficacy under field conditions is still a matter of debate (Mix, 1986). In addition to environmental variables (temperature, humidity, soil conditions), a number of biological variables are also important in this complicated system: the nematode actually vectors a bacterium that produces a toxin, that in turn is the real cause of termite mortality. The interactions among these variables, and their optimal states, must be better understood to validate and further develop this biological control agent.

Other nematode species, other bacteria, and pathogenic fungi also offer promise for biological control. The fungus <u>Metarhizium anisopliae</u>, for example, has performed very well in laboratory tests against <u>Reticulitermes</u> species (Preston et al., 1982).

Chemicals affecting insect behaviour (semiochemicals) may
70 also prove useful in termite control. Insects are dependant upon both "pheromones," intra-specific chemical messengers, and "allelochemicals," chemicals produced in their environment and used in orientation to food sources, etc. With blind insects such as subterranean termites, one would expect that such chemical compounds would be particularly important in communication and foraging.

Although the compounds responsible have not been identified, there is much experimental evidence that development of immature termites into specialized body forms (castes) is controlled at least in part by pheromones released by the other colony members (cf., Bordereau, 1985). Synthetic compounds known as "juvenile hormone analogues," which mimic naturally-occurring insect developmental hormones, interfere with normal caste proportions by promoting the development of excess soldiers within the termite colony. The mandibles (jaws) of the soldiers are enlarged and specialized for defense, prohibiting the soldiers from feeding themselves and making them dependent upon the worker caste for food collection. Thus, application of juvenile hormone analogues to the colony, generally in their food, has the effect of gradually starving the colony (Howard and Haverty, 1979). When incorporated into cellulose baits, these compounds offer promise for controlling *Reticulitermes* species. (Jones, 1984).

Termites also use pheromones to mark their foraging trails. Solvent extracts of the gland producing these pheromones readily elicit trail-following in *Reticulitermes* workers (Grace et al., 1988; Howard et al., 1976). The principal component of the trail pheromone of *R. virginicus* was identified as (Z,Z,E)3,6,8-dodecatrien-1-ol (Matsumura et al., 1968), and similar compounds may occur in other *Reticulitermes* species. *Reticulitermes hesperus* workers respond differently to different concentrations of trail pheromone, and are able to detect a gradient of pheromone on a trail (Grace et al., 1988). Compounds such as these may prove useful both in encouraging termite feeding on poisoned baits, and in actually directing termite foraging in a particular direction, such as away from structural timbers and towards a toxic bait.

Wood decayed by certain fungi also contains chemicals which induce trail-following in termites, or arrest them at baits. Decayed wood baits impregnated with a slow-acting toxicant (Esenther and Beal, 1979) or a juvenile hormone analog (Jones, 1984) have been demonstrated to suppress termite activity. In fact, the first field trials of this technique were performed in Ontario (Ostaff and Gray, 1975). The success of this technique depends upon (1) an appropriate arrestant or feeding stimulant, (2) a nonrepellent and slow-acting toxicant, and (3) proper placement of the baits to intercept foragers.

Termites appear to have feeding preferences (cf., Cooper and Grace, 1987), and compounds that influence termite survival and behaviour are found in undecayed wood from many tree species. Many chemical compounds are present in plants, and a variety of feeding (survival) and orientation assays must be performed with the wood from each tree species to identify all of the possible effects. These effects can include: feeding toxicity, contact toxicity, fumigant action, feeding deterrence, feeding stimulation, attraction, arrestment, repellency, or induction of trail-following behaviour. For example, a solvent extract of the Costa Rican tree Tabebuia ochracea both repels and poisons subterranean termites, an extract of Lysiloma seemanii is toxic but elicits no effect on orientation behaviour, and an extract of Pinus ponderosa is toxic and also has attractant and/or arrestant qualities (Grace et al., in preparation).

Certain plants also contain compounds which neither repel nor kill termites, but deter feeding by them. Grace et al. (1986) found that termites fed significantly less on a Japanese rice paper manufactured in a traditional manner with starch from the plant Lycoris radiata as a binder, than on a rice paper in which the plant starch was processed to a greater extent, or one manufactured with a synthetic binder. Although the differences in feeding were significant, the differences in termite mortality on the three rice papers were not, indicating feeding deterrence as the mode of action and the reason why the "traditional" rice paper is reputed to resist deterioration.

The Multi-Tactic Approach

There are a variety of promising techniques on the horizon for controlling termites and other wood boring insects. However, no single technique, or research direction, should be expected to solve all of our problems. Rather, different techniques and combinations of techniques will be appropriate under different circumstances. Certainly, wood treatment, perhaps even with behavioral chemicals, is compatible with this approach.

This multi-tactic approach to pest management, in which the goal is to combine techniques to exert greater and greater pressure on the insect population, is a departure from the panacea of pesticide treatment. As discussed by Frankie et al. (1986), such "thoughtful" approaches to pest management necessitate well-trained technical personnel, and public acceptance of the higher costs inevitably associated with more highly trained personnel and more specific treatment methods. However, well-publicized concerns for human health and the environment are forcing the issue. As old methods of pest control fall by the wayside, innovative research, accompanied by public and professional educational efforts, will help us meet the challenge presented by wood destroying insects.

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