Structural pest management

Research shows that subterranean termites, in causing damage such as that shown here, establish pheromone trails, possibly to lead sightless workers to food. Attractants or repellents based on this trait may offer alternatives to current chemical methods of termite control.

The economic loss due to structural pests in California is immeasurable. The state's structural pest control industry, estimated at $300 million plus, consists of more than1,200 companies and 6,000 pest control licensees. In addition, consumers pay in excess of $50 million annually for over-the-counter pesticides for use in and around the house.

University of California scientists have taken the initiative in developing urban pest management during the last 30 years. These researchers and the Pest Control Operators of California recently joined forces to help provide additional professional training for the industry and stimulate research in urban pest management. The following articles on structural pests report on some of the current research in this field.

The search for new termite control strategies

Michael K. Rust ❑ J. Kenneth Grace ❑ David L. Wood
Donald A. Reierson

Because of the damage they do to wood structures and the anxiety they cause, termites are a major problem facing homeowners and lending institutions that finance home purchases. In California, more than 1.5 million structural inspection reports and 250,000 notices of completion of corrective work are filed each year with the Structural Pest Control Board. Over $360 million annually is spent in the state to control termites and other wood-destroying organisms. Fumigation and soil treatment with an insecticide are the most common methods of controlling drywood and subterranean termites, respectively.

Our research on termites at University of California, Riverside, has included identification of species, documentation of changes in distribution patterns, study of the effect of environment on colony growth and development, and evaluation of various strategies to lessen their economic impact. At UC Berkeley, chemicals produced and excreted by subterranean termites that affect behavior (semiochemicals) are being investigated in an attempt to find safer alternatives to the use of toxic chemicals for their control.

Drywood termites

Drywood termites excavate tunnel-like galleries in sound dead wood. A colony begins with a single queen and king and develops slowly over several years (fig. 1). The most common species in California is the western drywood termite, *Incisitermes minor* (Hagen).

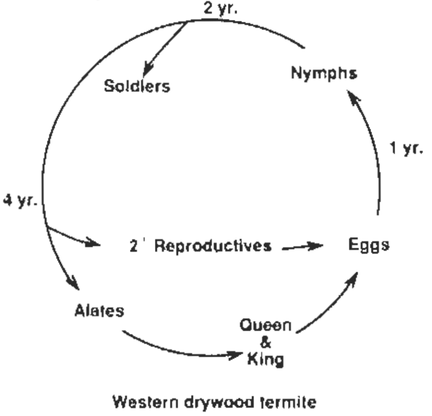

Fig. 1. Life cycle of the western drywood termite. Colonies develop slowly and may have only 50 nymphs after three years.

Drywood termites do not live in the soil and do not require soil contact as do subterranean termites. Drywood termites may infest lumber in subflooring, walls, attics, and roofs. Control may require expensive fumigations, because colonies often extend into inaccessible places. Surface sprays or powders cannot penetrate wood sufficiently to reach drywood termite galleries. As a labor-intensive alternative to fumigation, the galleries of infested wood may be injected with insecticide under high pressure. Generally, this method cannot eliminate drywood termites from the structure.

Besides having colonies in buildings, the western drywood termite is common in dead portions of trees and shrubs such as walnut, sycamore, eucalyptus, willow, almond, pyracantha, and rose bushes. These naturally occurring colonies may serve as sources for infestations of wood structures.

The extent to which the environment influences the distribution and success of termite colonies is largely unknown. As with many kinds of insects, it is presumed that temperature and humidity are critically important. It may be possible to produce lethal temperatures for termites inside structural wood, as proposed by C. Forbes and W. Ebeling (1987, *IPM Practitioner* 9[8]:1-5). We investigated the effect of temperature on termites' survival and rate of feeding to determine their temperature tolerance.

Termites for this study were late-stage (late-instar) *I. minor* nymphs removed from sycamore logs. We used immatures, because they are the most destructive stage of a colony. The nymphs were placed on preweighed pieces of Douglas-fir (about 8 grams) in closed styrene food cups and were maintained at 50 percent relative humidity at 60°, 70°, 80°, 90°, and 100°F (15.5° to 37.8°C). Five replicates were kept at each temperature for 14, 30, and 45 days. At the end of each trial, we counted surviving termites and measured the amounts of wood that had been consumed.

The optimum temperature for drywood termites was 80° to 90°F (26.2° to 32.2°C) (fig. 2). Termites held at 100°F died within two weeks. Although drywood termites are common where temperatures often exceed 100°F, they cannot withstand temperatures above 100°F for long periods. Exposure to 112°F (44.5°C) for just four hours was lethal to the western drywood termite under the experimental conditions.

Our studies support observations that drywood termite colonies in buildings in hot climates tend to be situated closer to the ground than those in more moderate climates. Some notions about the ability of western drywood termites to withstand very high temperatures like those in attics in southern California and Arizona need to be reconsidered in light of our findings.

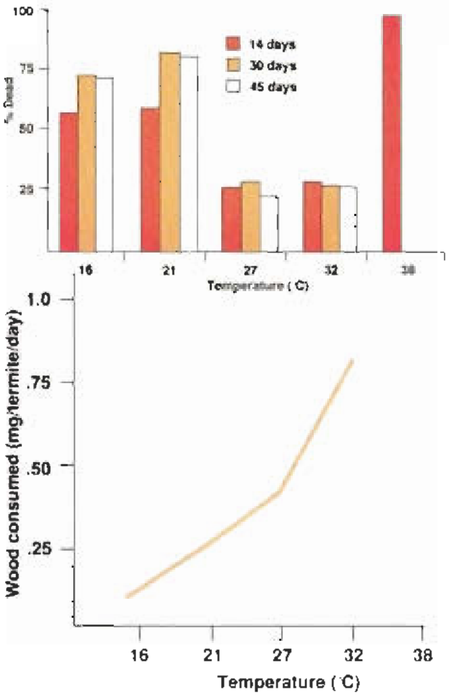

Fig. 2. Survival of drywood termites was highest at 80° to 90°F (26° to 32°C); they died in two weeks at 100°F. Wood consumption was low, even at most favorable temperatures.

We were surprised to find how little wood was eaten by the termites in our temperature study. After mortality was accounted for, a termite ate only 0.59 mg wood per day (range 0.33 to 0.86 per day) under optimal conditions. Based on these findings, a large drywood termite colony containing about 1,000 late-instar nymphs under ideal conditions would consume about 0.5 pound (0.25 kg) of wood per year. Drywood termite colonies develop slowly, with usually no more than about 50 nymphs three years after the start of a colony and about 1,000 nymphs after seven years. This information reinforces the general belief that it usually takes many years for drywood termites to do significant damage to structures. Of course, multiple colonies, reinfestation, and ideal conditions might eventually contribute to more severe problems.

Findings from simple feeding and temperature exposure studies indicate that drywood termites consume relatively small amounts of wood and have narrower temperature tolerances than previously assumed. New management concepts incorporating this and other biological information about drywood termites need to be developed.

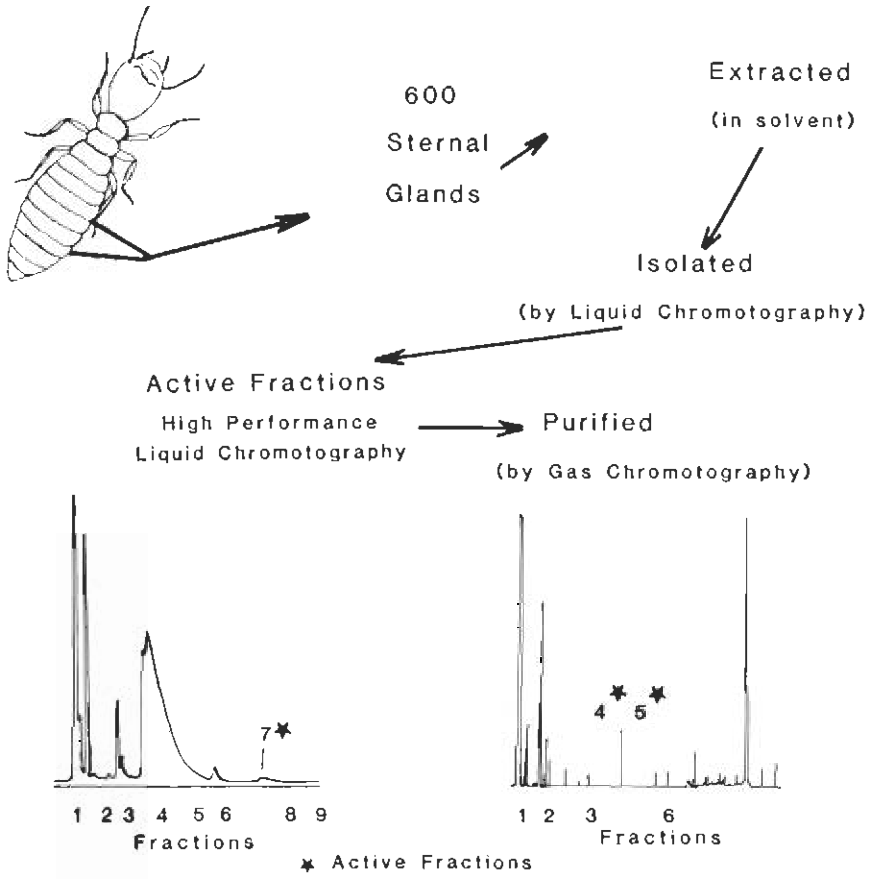

Fig. 3. Procedure by which researchers isolate the trail pheromone from glands on two abdominal segments of the western subterranean termite. In tests of various dilutions of the extract, workers followed an increasing concentration but turned around and walked away when the concentration was decreased.

C. Jourdain

Termites develop slowly with primary queens, such as that shown here, laying clutches of 1 to 12 eggs daily. Supplemental queens are more active, and colonies of the subterranean termite may eventually reach millions of individuals. Drywood termite colonies are much smaller, numbering as few as 1,000 after seven years.

Studies show that it takes many years for drywood termites to do significant damage to wood such as this laminated Douglas-fir roof beam. Drywood termites consume smaller amounts of wood and have narrower temperature tolerances than was previously assumed.

Subterranean termites

Subterranean termites establish chemical trails with pheromones secreted by the worker termite from its sternal gland, which is on the lower part of the fifth abdominal segment (fig. 3). The trails are believed to help termites recruit workers to a newly discovered food source. Attractants and repellents offer a promising alternative to current treatments for termite control. Termites could be attracted or diverted by trail pheromones to toxic wood bait blocks, sticky traps, or other types of traps.

The trail pheromone of the southern subterranean termite, *Reticulitermes virginicus* (Banks), has been identified from homogenized whole insects, including their digestive systems. The pheromone has also been isolated and identified from wood decayed by the brown-rot fungus *Gleophyllum trabeum* by G. R. Esenther, F. Matsumura, and co-workers (University of Wisconsin).

Research at UC Berkeley on termite trail-following has employed solvent extracts of the fourth and fifth abdominal segments of the western subterranean termite, *Reticulitermes hesperus* Banks, that contain the sternal gland, rather than using whole-body homogenates. This dissection is quite labor-intensive but provides concentrated material and eliminates any question of a dietary origin of the pheromone (table 1). Isolation of active components is being conducted in collaboration with Professor I. Kubo (Department of Entomological Sciences, UC Berkeley).

We have developed a simple test for comparing the behavioral activity of different extracts. The speed with which termites follow trails is closely related to perception of the trail-following stimulus. In our test, "speed" is expressed as the distance traveled on an artificial trail in 30 seconds. Reversing direction on the trail before reaching the end is related to the intensity of stimulation. Thus, the distance traveled is actually a composite of the rate of motion and the number of turns on the trail.

Our test allows clear separation of termite responses to various dilutions of sternal gland extract (table 2). Including a series of solvent blank trials among each set of treatment tests permits more quantitative results than simple (+) or (-) assays that pair each individual extract trail with that of a solvent control trail.

With modification of our basic bioassay, we have demonstrated that western subterranean termite workers will follow an increasing concentration of trail pheromone, and will turn around and walk in the opposite direction when exposed to a decreasing concentration. This response suggests that termites could mark their trails to influence direction, possibly by concentration of pheromone deposition in specific portions of the subterranean gallery system.

We have also begun to investigate the semiochemicals found in plant material fed upon by the western subterranean termite. These include both plant-derived compounds and chemicals that either are fungus-derived or come from the interaction between decay fungi and the cellulose substrate.

Our assays are intended to identify the specific behavioral or physiological effects of compounds extracted from plant material

TABLE 1. Trail-following by *Reticulitermes hesperus* workers on artificial trails drawn with extracts of different portions of termite bodies*

Tissue	Avg. distance†
	mm
Body	138.3 a
Sternite 4, 5	130.8 a
Abdomen	79.2 b
Thorax + head	1.7 c
Solvent only (control)	2.0 c

* Aliquots from 1-min. solvent extraction were applied to a 200 mm line with a microliter syringe at rate of 1/50,000 termite equivalents per mm.

† Repeated 25 times. Means followed by the same letter are not significantly different (ANOVA of ranked data values, Ryan-Einot-Gabriel-Welsch multiple range test, $P = 0.05$).

TABLE 2. Average distance traveled in different time intervals by *R. hesperus* workers on 200 mm artificial trails of sterile gland extract

Trail concn. gland equiv. per mm	Average distance per time interval*			
	0.5 min	*1 min*	*2 min*	*3 min*
		mm		
2×10^{-4}	182 a	187 a	191 a	188 a
2×10^{-5}	87 b	111 b	115 b	131 b
2×10^{-6}	8 c	11 c	23 c	15 c
Solvent only (control)	3 c	3 c	3 c	3 c

* Treatment $n = 25$. Means followed by the same letter in each row and column not significantly different (ANOVA of rank values, REGW multiple range test, $P = 0.05$).

(in collaboration with Professor G. W. Frankie, Department of Entomological Sciences, UC Berkeley). In tests where 18 groups of 40 *R. hesperus* workers were confined in 1-ounce plastic cups in a humidity chamber (19° to 24°C, 94±5 percent relative humidity), there was no mortality over a five-day period among those confined in alpha-cellulose and in Douglas-fir (*Pseudotsuga menziesii*) sawdust.

Survival after 45 days was greater in Douglas-fir sawdust that had been heavily mined by the colony from which the test individuals had been removed (13 percent mortality) than in Douglas-fir sawdust equally available to the colony but mined only slightly (19 percent mortality) or in alpha-cellulose (26 percent mortality). By contrast, very high mortality was noted after five days in heartwood sawdust of two Costa Rican species, *Lysiloma seemannii* (65 percent mortality) and *Tabebuia neochrysantha* (95 percent mortality). Both of these hardwoods are locally reputed to be resistant to insect attack and fungal decay.

To date, we have isolated two wood-decaying Basidiomycetes fungi from wood infested by *R. hesperus* in the San Francisco Bay Area (in collaboration with Professor W. W. Wilcox, Forest Products Laboratory, UC Berkeley). Decay tests with white fir and red alder sapwood blocks indicated that one of these fungi is an active decay species, while the other decays both types of wood more slowly. We have extracted white fir blocks (averaging 22 percent weight loss) decayed by the more active fungus and conducted preliminary tests of these extracts for their ability to induce trail-following in *R. hesperus* workers. On a weight comparison basis, the fungus-decayed wood demonstrated trail-following activity that was 1/120,000 that of extracts of the termites' sternites containing the pheromone-producing gland.

Conclusions

In the future, strategies for controlling drywood and subterranean termites may increasingly rely on the basic information generated from such studies as have been conducted at UC Berkeley and Riverside. With the ever-increasing concern by the public about toxic substances, the use of heat or semiochemicals may become attractive alternatives to the pest control procedures used at present.

Michael K. Rust is Professor and Donald A. Reierson is Staff Research Associate IV, Department of Entomology, University of California, Riverside; J. Kenneth Grace, former graduate student at UC Berkeley, is now Associate Professor, Faculty of Forestry, University of Toronto; and David L. Wood is Professor and Chairman of the Department of Entomological Sciences, UC Berkeley.

Insecticide resistance affects cockroach control

Donald A. Reierson ❑ Michael K. Rust ❑ Arthur J. Slater
Timothy A. M. Slater

Despite the extensive use of insecticides, cockroaches remain one of the most widespread and troublesome of California's household and commercial pests. There are several species of cockroaches in California, but the German cockroach, *Blattella germanica* (L.), is by far the most pestiferous. German cockroaches commonly infest restaurants, grocery stores, hospitals, jails, hotels, homes, apartments, and just about any place where food is regularly prepared or stored. They are often associated with unsanitary conditions and are potential mechanical transmitters of a variety of pathogenic bacteria and viruses. Some people develop contact or inhalant allergic reactions to the

The German cockroach (above) is the most common and troublesome of those found in California, but the brownbanded cockroach (below) is reported to be increasing in some areas. Though roaches are easily killed by available insecticides in laboratory tests, field-trapped specimens often are resistant to chemical control.