(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

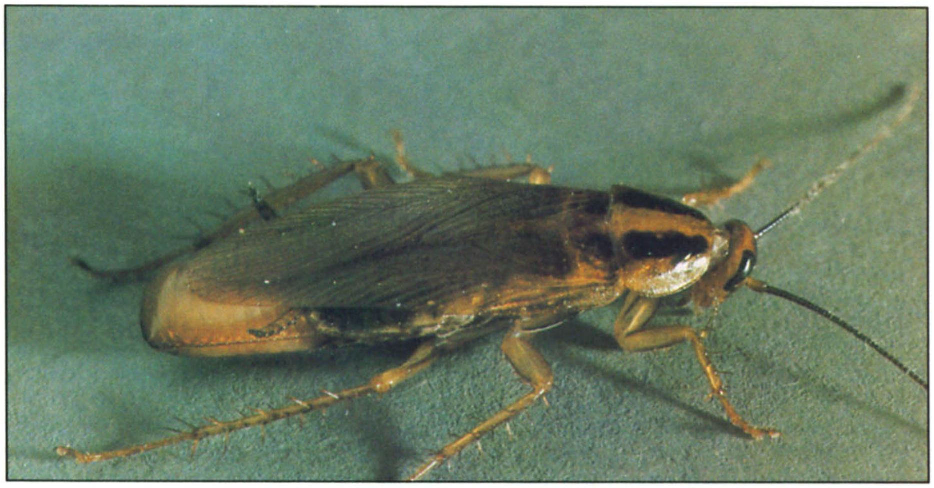
In the future, strategies for controlling drywood and subterranean termites may increasingly rely on the basic information generated from such studies as have been conducted at UC Berkeley and Riverside. With the ever-increasing concern by the public about toxic substances, the use of heat or semiochemicals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

skins or droppings of cockroaches. Such reactions may include hives or rashes, coughing, sneezing, or shortness of breath.

Regular insecticide application by the homeowner or a commercial applicator is the most common control strategy. Generally, treatments are applied to sites where cockroaches have been seen and where they are suspected to be living. Their close association with people and food, the ability of their populations to expand rapidly, and their tendency to gather in inaccessible places make it particularly difficult to treat cockroaches effectively and eliminate them once they become established.

There is controversy concerning the major reasons why German cockroaches continue to be so difficult to eradicate. Most insecticides available to consumers and commercial applicators are highly active against cockroaches; less than 0.4 microgram is enough to kill a laboratory-reared insect. A few ounces of dilute spray contains enough insecticide to kill more than two million cockroaches. Nonetheless, control failures are common.

Poor application may be partly responsible, but there may be other contributing reasons. Exposed cockroaches can be killed with nearly any toxic spray, but overall good control of those living in inaccessible sites is achieved by thoroughly treating cracks, crevices, and other places likely to be walked on by cockroaches. Some insecticides are ineffective because they are not directed to areas where cockroaches will contact them, are absorbed into surfaces, or for some other reason are not readily picked up by the insects; some chemicals are relatively inactive at temperatures preferred by cockroaches; and some are repellent so that cockroaches avoid contacting them.

Because of a large number of control failures with no apparent relation to method of application, and because of the current heavy reliance on chemical insecticides, we suspected that insecticide resistance might also be contributing to poor control. We designed a series of studies to determine the magnitude and extent of insecticide resistance in urban cockroach populations.

Cockroach samples

We asked cooperators to send us live German cockroaches from specific sites where control failures were occurring. We began receiving samples in 1980 from several localities in California and from eight other states, Canada, and Mexico. We received 45 collections, whose numbers were expanded in the laboratory until we had enough insects to screen for resistance.

In 1982, we screened for cockroach resistance in 100 restaurants in the greater Los Angeles area. This survey was conducted without regard to control failure history. The restaurants ranged from small to large and from new to old; all were receiving some kind of commercial pest control service. We collected cockroaches with six greased can traps baited with fresh bread in each restaurant. As before, the insects we collected were reared for subsequent resistance screening.

Resistance in collected strains

Through applications of insecticides directly to roaches (topical applications) and confinement of roaches to insecticide-treated panels, we found that insecticide resistance among these insects was widespread. Although there was considerable variation in response among strains, some level of resistance was common. For instance, 71 percent of the field-collected strains had at least five-fold resistance to chlorpyrifos (Dursban). There was measurable resistance in each of the 45 strains from locations where there had been control problems and in about two-thirds of 48 strains we collected in our random sampling of 100 restaurants. (We actually saw or trapped cockroaches in 66 of the restaurants, but were able to rear colonies from 48 of them.)

Cockroaches from restaurants receiving regular pest control service could generally tolerate about 5 to 10 times the dose of organophosphorus insecticides and 300-fold doses of carbamate insecticides that would normally kill nonresistant laboratory cockroaches (table 1). There was also resistance to previously unused new compounds such as cypermethrin (Ammo; Demon), indicating that broad-spectrum resistance to apparently unrelated kinds of insecticides had developed.

Relevance of resistance

We found that a low level of resistance was sufficient to allow for increased survival and resultant poor control. With Dursban as a model, table 2 shows the difference in knockdown between lab-strain and field-collected cockroaches exposed for up to 60 minutes to insecticide spray residues. A day after exposure, all of the lab cockroaches were dead but no more than 25 percent of the field-collected cockroaches were dead. Similar results were found with other insecticides to which cockroaches have become resistant.

In instances where resistance affords protection, and prolonged exposure does not provide mortality, the insects may avoid the treatment and survive in an untreated area. For example, neither Baygon (propoxur) nor Dursban in a choice test was as effective against a resistant strain as against a susceptible lab strain (table 3). In these tests, the treatments were presented in a two-compartment box in such a way that cockroaches could avoid an insecticide in a dark portion of the box by residing in a less-preferred lighted area. Results of the choice box tests correlate very closely with our monitoring of treatment efficacy under field conditions. Because of their high fecundity (about 30 to 50 young per egg capsule every three weeks), even 83 percent kill (17 percent

TABLE 1. Insecticide resistance of German cockroaches collected from randomly selected restaurants, Los Angeles

Insecticide		Number strains tested	Resistance ratio*	
Category	Toxicant		Avg. ± SD	Range
Carbamate	Propoxur	24	308.0 ± 45.5	161.0-322.0
Phosphate	Acephate	20	4.6 ± 3.6	1.3- 15.2
	Chlorpyrifos	22	5.4 ± 3.4	1.3- 13.0
	Propetamphos	25	4.8 ± 7.5	1.3- 10.0
Pyrethroid	Cypermethrin	22	6.0 ± 3.6	1.6- 13.3
Cyclodiene	Chlordane	19	1.1 ± 0.8	0.3- 3.4

* Topical LC_{50}/24 hours (concentration lethal to 50 percent of test population at 24 hours), of F-3 to F-4 (third- and fourth-generation) males, compared with nonresistant lab strain (Orlando Normal).

TABLE 2. Effect of resistance on survival of adult German cockroaches exposed for limited periods to deposits of Dursban LO (chlorpyrifos) on Masonite

Exposure	Conc.*	Mortality at 24 hours	
		Lab	Resistant†
min	*% AI*	*%*	*%*
15	0.50	100	0
	0.25	0	0
30	0.50	100	0
	0.25	100	0
60	0.50	100	25
	0.25	100	25
	0.125	100	0

* Concentration (% active ingredient): aqueous deposits dried 1 day; 0.50% = 30 mg AI per 100 sq. ft.
† Field-collected strain, about 10-fold resistant to chlorpyrifos.

TABLE 3. Effect of resistance on effectiveness of residual deposits of Baygon (propoxur) and Dursban (chlorpyrifos) against German cockroaches in choice boxes

Treatment	Strain*	Mortality at day:		
		1	7	14
		%	%	%
Baygon, 1%	S	25	92	93
	R	3	22	25
Dursban, 0.5%	S	80	95	100
	R	0	70	83

* S = susceptible lab strain; R = field-collected strain, 120-fold resistant to propoxur and 10-fold resistant to chlorpyrifos (topical LC_{50}/24 hours).

Case study: A cockroach management program in University housing

We reviewed reports of cockroach problems over 18 years (1969 through 1986) from a complex of 920 apartments to evaluate the pest control programs and design more effective ones. The 4,390 special report forms originated as complaints from occupants of the Albany Village married students' apartments of UC Berkeley. Information on the forms, which were completed after pest control service had been provided by a technician, included the target pest and the date, location, and specifics of the treatment.

Of the 104 buildings in the complex, 54 were built in the 1940s, and 50 in the 1960s. About 15 percent of the apartments are treated annually for cockroaches and, when adjusted for the number of apartments in each group, twice the number of older apartments have needed treatment. The trends and performance of the management program are shown in figure 1.

Reliance on 1 percent diazinon plus 0.5 percent dichlorvos (Vaponite), an organophosphorus combination spray, from 1969 to 1974 resulted in insecticide resistance, control failures, and spread of the cockroach problem. Within five years, the number of apartments needing treatment for cockroaches during the year increased 50 percent, from 138 to 207, and the number of apartments needing more than one treatment increased from 32 to 51 (59.4 percent). By 1973, technicians began noting regularly that the diazinon-dichlorvos mixture was no longer effective.

We abandoned that mixture in 1974 and started to use a synergized pyrethrin spray (Pyrenone). Pyrethrins quickly knock down cockroaches, are highly repellent, and have no long-lasting effect. Within a year, 84 apartments (33.6 percent of 250 treated) needed to be sprayed two or more times to gain satisfactory control, an additional 65 percent increase. By 1975, because of resistance and repellency, 381 treatments were needed compared with 180 in 1969. Cockroaches collected from the apartments were resistant to diazinon, and it is likely that dichlorvos and pyrethrins, chemicals repellent to cockroaches, worsened the problem.

Boric acid powder was blown into wall voids in the older buildings in 1974-75. The powder prevented cockroaches from living in the walls and moving between apartments. The number of complaints and treatments needed for control in those buildings during 1976 was halved and shows the value of this kind of treatment. There are no reports of cockroaches being resistant to boric acid.

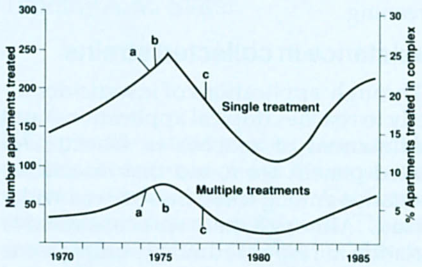


Fig. 1. Cockroach treatments at Albany Village, UC Berkeley student housing: (a) discontinued diazinon + DDVP, began using pyrethrins; (b) boric acid powder blown into walls of all older apartments (420 of 920); (c) discontinued pyrethrins, began using encapsulated diazinon.

Use of the pyrethrin spray was discontinued in 1978 as microencapsulated diazinon (Knox Out 2FM) began to be used. It had been reported that Knox Out was effective against resistant cockroaches, and it did provide improved control for about four years. Then the number of control failures began increasing again. By 1983 we had as many annual complaints as in 1978. The lack of long-term control with the encapsulated formulation is not surprising, since the same organophosphorus active ingredient had been used for cockroach control in the complex for several years previously.

Although the German cockroach has been the major cockroach pest in these apartments, we have noticed an increasing presence of the brownbanded cockroach, *Supella longipalpa* (Serville). This species prefers warmer conditions and may be replacing the German cockroach in importance at the Albany Village. Based on records and observations from other Berkeley campus buildings, treatments to control German cockroaches are often not effective against the brownbanded roach. The growing number of complaints about cockroaches in the Albany Village complex since 1983 may be due to the greater incidence of the brownbanded cockroach.

survival) of cockroaches allows for rapid reinfestation and increased tolerance of insecticide.

About 10-fold resistance (topical LC_{50} per 24 hours—the concentration required to kill 50 percent of the test population in 24 hours) was the critical point above which control failures were common. Inconsistent levels of control were achieved when resistance was 5- to 10-fold, and good control was generally obtained when resistance was below 5-fold.

Conclusions

German cockroaches are widespread and difficult to control. Although other factors may contribute to poor control, insecticide resistance is often associated with control failures. Lab tests showed that a low level of resistance, on the order of 5- to 10-fold, could result in control failures. As seen in the case study in student housing, multiple applications of the same kind of insecticide and the use of repellent chemicals may result in poor control because of resistance and spread of cockroaches to untreated sites. Less than thorough treatments with insecticides of similar chemical structure may aggravate the problem.

Taking into account the impact of resistance, a long-term program to control German cockroaches should incorporate a variety of techniques: (1) population sampling and monitoring to minimize the number of treatments needed; (2) rotation of different categories of insecticides, including insect growth regulators and inorganic materials such as silica aerogels and boric acid; (3) emphasis on nonrepellent chemicals; (4) the possible use of baits, hyperthermia (high temperature), cryogenics (freezing), fumigation, and other methods to destroy cockroaches in specific sites without leaving residues to which the cockroaches will become resistant; (5) good construction and treatment practices to minimize passages and hiding places for cockroaches (treatment of wall voids and similar spaces with long-lasting inorganic insecticidal powders [built-in control] keeps cockroaches from escaping treatments and moving into untreated areas); and (6) good sanitation, which also reduces cockroach hiding places and minimizes interference of grease and other surfaces that absorb chemicals applied for control.

Donald A. Reierson is Staff Research Associate IV, and Michael K. Rust is Professor of Entomology, Department of Entomology, University of California, Riverside; Arthur J. Slater is Senior Management Support Technologist, Office of Environmental Health and Safety; and Timothy A. M. Slater is a student in the Department of Physics, University of California, Berkeley.