Relation Among Efficacy of Insecticides, Resistance Levels, and Sanitation in the Control of the German Cockroach (Dictyoptera: Blattellidae)

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ABSTRACT The efficacy of several insecticides for controlling the German cockroach, *Blattella germanica* (L.), was compared in field and laboratory tests. Based on trap catch before and after treatment in a multiunit public housing complex, 0.2% cypermethrin was more effective than 0.5% chlorpyrifos or 1.1% propoxur. Up to 3 mo of residual activity was achieved with cypermethrin. A positive correlation was confirmed between poor sanitation and higher cockroach populations. Improved sanitary conditions increased the efficacy of some insecticide treatments. Cockroaches collected from apartments where these tests were done were >100 times as resistant to propoxur and bendiocarb, and 4.51, 1.34, and 1.84 times as resistant to cypermethrin, chlorpyrifos, and diazinon, respectively (continuous exposure surface contact test).

KEY WORDS Insecta, *Blattella germanica*, sanitation, resistance

CURRENT RECOMMENDATIONS for control of the German cockroach, *Blattella germanica* (L.), in multiunit housing center on an integrated approach that includes monitoring of sanitation, pest populations, resistance to insecticides, residents' attitudes, and applications of insecticides. Central to such recommendations is an evaluation of the relationship between insecticide resistance profiles of field-collected insects and the efficacy of various insecticides against these insects. The German cockroach has a well documented history of developing resistance to various insecticides. Therefore, it is important to relate field efficacy data to resistance profiles so that the efficacy and utility of insecticides currently in use may be extended, and to prevent or delay development of resistance to new insecticides.

In this report I examine the efficacy of representative organophosphate, carbamate, and pyrethroid insecticides for controlling German cockroach populations in multiunit apartment complexes, the relationship between sanitation and cockroach populations in untreated and insecticide-treated apartments, and the relationship between efficacy of insecticides in the field and levels of insecticide resistance determined in the laboratory.

Materials and Methods

Site Description. Field tests were conducted from April to September 1985 in cooperation with the Jersey City Housing Authority, Jersey City, N.J., in a multiunit brick building. Floors 2 through 10 were used in the 10-story building. Each floor contained eight apartments, four on each side of an elevator. A refuse shaft next to the elevators led to an incinerator in the basement. Each apartment contained a kitchen–dining room and a living room, both with windows, one to three bedrooms, and a bathroom. The kitchen contained a utility closet where many residents stored refuse before disposal. The building was supplied with a hot-water heating system.

Kitchen sinks were always laid in a wood cabinet with voids at its far end and underneath. Wooden cabinets were also present above the sink. Bathroom sinks were supported by brackets attached to the wall. No cabinets were present in the bathroom except a metal medicine cabinet. All bathrooms contained a full-sized bathtub. Generally, water leaks around plumbing fixtures and old, inadequately maintained cabinets supported large German cockroach populations.

Test Design. Owens (1980) and Ballard & Gold (1983) reviewed the use of sticky traps for assessing populations of the German cockroach. Two molasses baited sticky monitoring traps (Roach Pot) were placed in the kitchen and one trap was placed in the bathroom of all apartments. Traps were collected after three nights to assess pretreatment and posttreatment population levels. Apartments in which more than 20 cockroaches were captured were assigned randomly to four treatments. The treatments were an untreated control, 1.1% (AI) propoxur (Baygon Wettable Powder [WP], Mobay Chemical Corp., Kansas City, Mo.), 0.2% and 0.1% (AI) cypermethrin (Demon WP, ICI Americas, Pikeville, N.C.), and 0.5% (AI) chlorpyrifos (Dursban Low Odor emulsifiable concentrate, Dow Chemical Co., Midland, Mich.)

The insecticides were each mixed into new 3.785-liter (1 gallon) compressed air sprayers and dispensed using the pinstream nozzle setting. After residents had emptied all kitchen cabinets, kitchens and bathrooms were treated. Approximately 1 liter (1 qt) of an insecticide solution was applied in each apartment, mainly in cracks and crevices, around and under appliances, along baseboards, and in and behind cabinets. Identical treatments were repeated after 3 mo, but cypermethrin was applied at a rate of 0.1%.

The number of cockroaches per apartment was converted to percentage of pretreatment and subjected to statistical analysis after angular transformation. Unless otherwise specified, treatments were compared by analysis of variance (ANOVA) and Duncan's (1955) multiple comparison of means (SAS Institute 1985) after each trapping session. Changes in trap catch over time within treatments were compared with pretreatment trap catch using Wilcoxon's signed rank test (SAS Institute 1985).

Midway through this project (before the second insecticide application at month 3), an evaluation of the degree of sanitation in each apartment was made. A scale of 1 (fairly clean) to 5 (severely dirty) (modified from Bennett [1978]) was used to rate degree of sanitation as follows:

1. Fairly clean, not cluttered, no obvious piles of trash.
2. Fairly clean, but cluttered, appliances with some dirt.
3. Generally dirty, but not cluttered, floors and walls dirty, cupboards dirty but not cluttered, kitchen appliances dirty.
4. Generally dirty and cluttered with obvious garbage, cupboards dirty, appliances greasy, floor dirty, unwashed dishes.
5. Severely dirty and cluttered with obvious garbage, large greasy areas on counters and appliances, dead cockroaches not swept up, left-over food on counters.

The relationships among sanitation, trap catch, and efficacy of insecticides were assessed with Pearson's correlation analysis (SAS Institute 1985).

Resistance Evaluation. At the conclusion of this study, cockroaches were collected from five apartments in the treated building (two on the fifth floor, one on the ninth, two on the tenth) and an additional apartment operated by the same housing authority ca. 5 km from the test site. Cockroaches were collected in bread-baited Mason jars whose rims had been coated with petroleum jelly to prevent escape of the cockroaches.

A modified World Health Organization (1970) tarsal-contact test was conducted on males two to six generations after field collection. Technical insecticide was applied in 2.5 ml acetone to a 0.47-liter (1 pint, 243 cm^2) mason jar. The acetone was evaporated and the jar ventilated for 60 min. Ten unanesthetized male German cockroaches were placed in each of three jars (30 males per strain per insecticide) and monitored at 2.5-min intervals at 27°C. Using SAS programs (SAS Institute 1985), mortality values were transformed to probits, and lethal times required to kill 50% (LT_{50}) and 95% (LT_{95}) of the cockroaches were obtained for field collected and susceptible (Virginia Polytechnic Institute [VPI] strain) cockroaches. Resistance ratio (RR) is defined as the LT_{50} for each field-collected strain divided by the value for VPI-normal cockroaches.

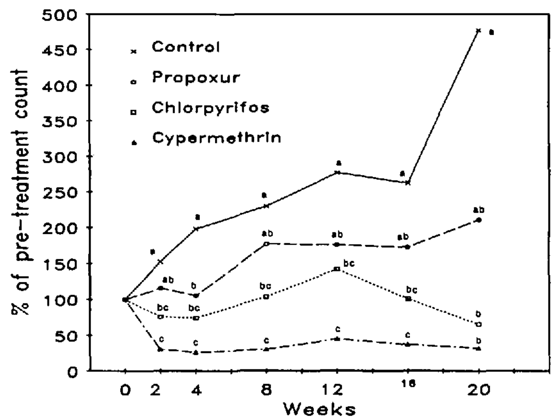

Fig. 1. Field test results with three insecticides and a control in apartments infested with German cockroaches. All values are percentage of trap catch relative to trap catch before treatment. Means of treatments for each time period followed by the same letter are not significantly different (P = 0.05; Duncan's [1955] multiple range test [SAS Institute 1985] after angular transformation of percentage increase or decrease in trap catch relative to catches before treatment).

To determine dosages for the contact WHO test (LT_{50} value of 30–60 min), standard dose–response regressions were obtained for technical chlorpyrifos R (99%, Dow Chemical Co., Midland, Mich.), cypermethrin (92.7%, Fairfield American Corp., Newark, N.J.), propoxur (99%, Mobay Chemical Corp., Kansas City, Mo.), diazinon (88.4%, CIBA-Geigy Corp., Greensboro, N.C.), and bendiocarb (95%, Nor-Am Chemical Co., Kansas City, Mo.). As described above, 30 males were used for each dose–insecticide combination. At least five concentrations were tested for each insecticide. Synergism of propoxur with piperonyl butoxide was tested with cockroaches collected in only one apartment. Twenty micrograms piperonyl butoxide (90%, Fairfield American) in acetone was applied topically to males 2 h before testing; control males were treated with 2 μl acetone.

Results

Population Reduction. In untreated apartments, a 2.8-times increase in trap catch occurred after 3 mo and a 4.8-times increase was observed over the 5 mo of the study (Fig. 1; Table 1). In apartments treated with propoxur, trap catch remained unchanged for the first 2 mo; the number of cock-

Table 1. Comparison of percentage increase and decrease in cockroaches over time in a field test with three insecticides and a control in apartments infested with German cockroaches

Treatment	n	% concn (wt-vol)	After treatment[a]					
			2 wk	4 wk	8 wk	12 wk	16 wk	20 wk
Control	12	—	NS	B	A	A	A	B
Propoxur	13	1.1	NS	NS	A	A	NS	NS
Chlorpyrifos	12	0.5	NS	a	NS	NS	NS	a
Cypermethrin	11	0.2	c	c	b	b	a	b

[a] Statistical analysis of trap catch within treatments (rows) over time. The median trap catch was compared with the trap catch before treatment by Wilcoxon's signed-rank test (two-tailed) (SAS Institute 1985). NS, not significant; a or A, $P < 0.05$; b or B, $P < 0.01$; c or C, $P < 0.001$. Capital letters denote increase above counts before treatment; lowercase letters represent decreases.

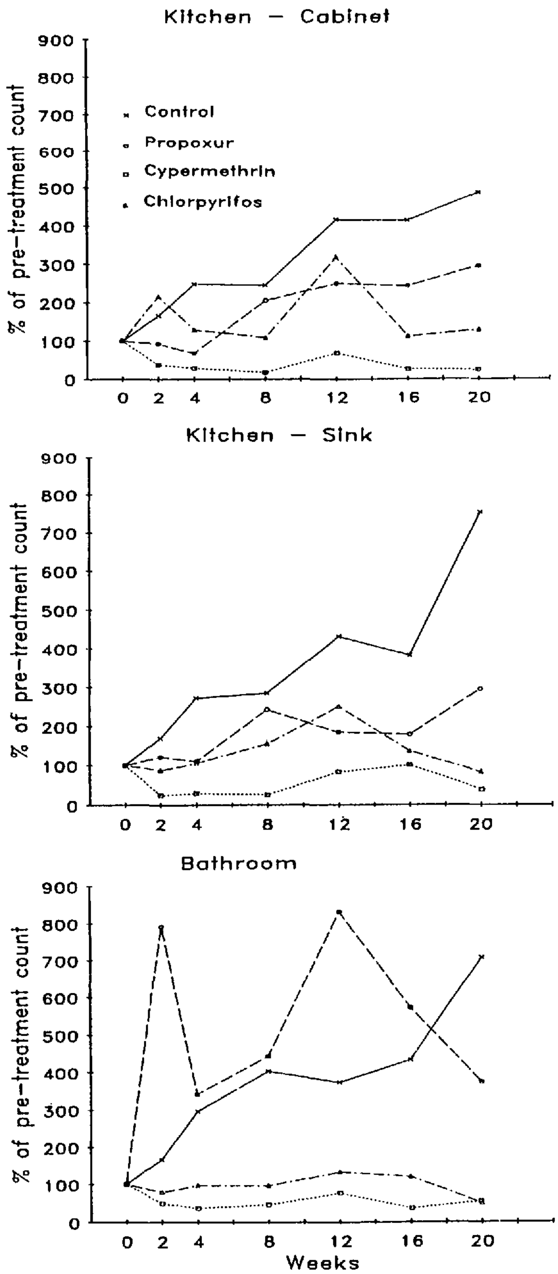

Fig. 2. Field test results separating trap catch by location.

roaches trapped increased by 75 and 111% (above levels before treatment) after 3 and 5 mo, respectively (Table 1). Apartments treated with chlorpyrifos experienced a 26% reduction in trap catch after the first month, but the number of cockroaches captured increased through the second treatment (3 mo). Trap catch was significantly ($P < 0.05$) reduced to 65% of the count before treatment at the conclusion of the test (Table 1). Cypermethrin clearly resulted in the greatest and most rapid decline in trap catch. Two months after treatment, trap catch was only 26% of counts before treatment; a slight, insignificant ($P > 0.05$) increase observed by 12 wk was reduced to 32% by 5 mo (Fig. 1; Table 1).

Multiple comparisons of means (ANOVA, Duncan's [1955] multiple range test on angular transformed values) indicated that cypermethrin and chlorpyrifos-treated apartments had significantly lower trap catches than untreated apartments for all six trapping sessions after treatment (Fig. 1). This was true for apartments treated with propoxur only on one occasion (1 mo after treatment).

Distribution Within Apartments. The change in trap catch over time was the same for kitchens and bathrooms in untreated apartments. Within the kitchen, trap catch under the sink was 753% of numbers before treatment by the fifth month, whereas trap catch in the dish cabinet above the sink increased to 485% (Fig. 2).

In propoxur treatments, reduction in the population in the bathroom was lower than in the kitchen; by 3 mo, trap catch increased 8.3 times in the bathroom compared with 1.8 and 2.5 times under and above the kitchen sink, respectively. In chlorpyrifos-treated apartments, changes in trap catch were similar in the kitchen and bathroom until month 2. By month 3 (before second treatment), traps in the kitchen caught 2.5 and 3.2 times more cockroaches compared with numbers before treatment, whereas the trap in the bathroom averaged a 1.3-fold increase in cockroaches. Trap catches decreased similarly following the second treatment.

In cypermethrin-treated apartments, reduction in cockroach numbers in the kitchen was greater than in the bathroom. Within the kitchen, control of cockroaches was more effective above than be-

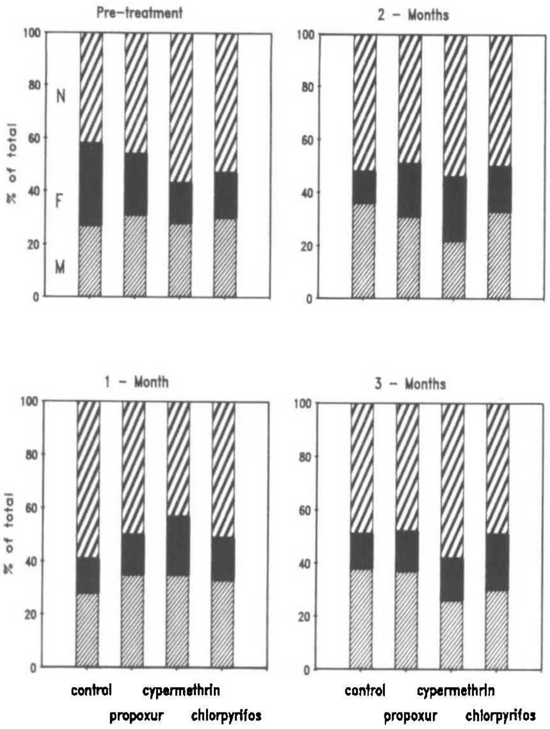

Fig. 3. The ratio of nymphs : females : males at four periods during the study and under four treatments. In each bar, top represents nymphs; center (black), females; bottom, males.

low the sink (Fig. 2), possibly because of the persistent wetness of surfaces under the sink.

Sex Ratios and Age. Comparisons of treatments over time may be confounded by the distributions of age and sex ratios before treatment. Control and propoxur-treated apartments had significantly more females and fewer nymphs than other apartments (ANOVA, Duncan's [1955] multiple range test, $P < 0.05$). The ratio of females to nymphs was not significantly different in propoxur-treated and control apartments. Over the course of the study, the percentage of females in untreated apartments declined as males and nymphs increased (Fig. 3).

In insecticide-treated apartments, no significant changes in the age-sex composition were detected (Fig. 3). Nymphs usually comprised ca. 50% of the trapped population, with the rest consisting of ca. 20% females and ca. 30% males. With the exception of cypermethrin at 1 mo after treatment, insecticide treatments did not affect the percentage of females with egg cases that were trapped (ANOVA, Duncan's [1955] multiple range test, $P < 0.05$) (Table 2).

Sanitation. The distribution of treatments among apartments of various sanitation scores was approximately equal. Poor sanitation was correlated positively with trap catch before treatment (Fig. 4). In untreated apartments, poor sanitation was also correlated positively ($P < 0.05$) with trap catch over time for all trapping sessions (r^2 ranged between 0.5827 and 0.852) (Fig. 5). Thus, whereas in clean apartments (rank 1), trap catch increased to 125% of the count before treatment, in severely dirty apartments (rank 5) trap catch was 500–800% of this count after 3–5 mo.

Table 2. Comparison of percentage females with egg cases in a field test with three insecticides and a control in apartments infested with German cockroaches

Treatment	Before treatment	After treatment		
		4 wk	8 wk	12 wk
Control	22a	25a	21a	15a
Propoxur	27a	24a	23a	26a
Chlorpyrifos	24a	30a	26a	34a
Cypermethrin	23a	42b	12a	19a

Means within rows followed by the same letter are not significantly different. $P = 0.05$; Duncan's [1955] multiple range test [SAS Institute 1985] after angular transformation of percentage increase or decrease in trap catch relative to catches before treatment.

For all insecticide treatments, no significant correlation was observed between sanitation and increase or decrease in trap catch for the first 2 wk after treatment. However, all three treatments exhibited a significant positive correlation by 2 mo. This relationship was best for cypermethrin, where a significant relationship was sustained throughout the study after week 2. As sanitation improved, so did the efficacy of cypermethrin treatment (r^2 = 0.3309, 0.4486, 0.3071, 0.3570, 0.4357 for 1, 2, 3, 4, and 5 mo, respectively; $P < 0.05$ for all regressions). A similar pattern was observed for chlorpyrifos on all but the last sampling date (5 mo). The poorest relationship between efficacy of insecticides and sanitation occurred with propoxur treatments; a significant positive correlation (r^2 = 0.4618) occurred only on the second month.

Resistance to Insecticides. Resistance ratios are presented in Table 3 for five apartments and an

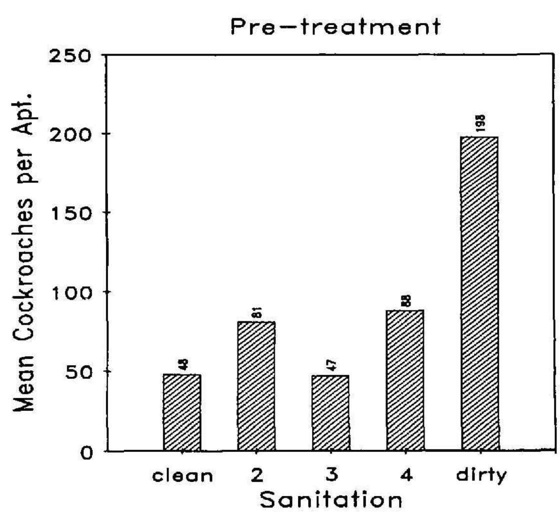

Fig. 4. Mean number of cockroaches per apartment related to degree of sanitation before treatment.

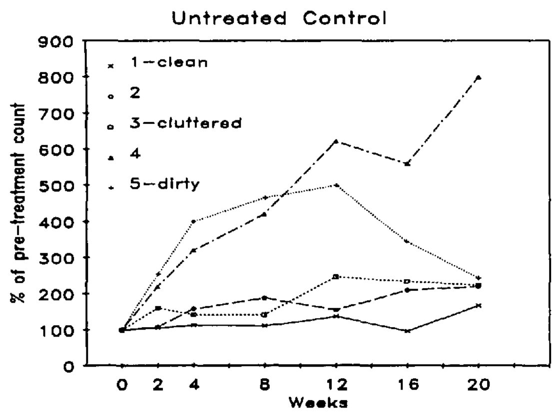

Fig. 5. Changes in trap catch over time in control apartments with different sanitary conditions. See text for detailed explanation of key.

apartment ca. 5 km removed from the test site. Cypermethrin resistance ratios averaged 4.51 (range 3.69–5.57). Chlorpyrifos resistance ratios at the test site ranged from 1.26 to 1.70 with an average resistance ratios of 1.34. Cockroaches in the single isolated apartment had an RR of 1.57 to chlorpyrifos. The LT_{95} for the VPI-normal strain decreased from 62 to 47 min when propoxur was synergized with piperonyl butoxide. However, the LT_{50} and LT_{95} for the field-collected cockroaches were >100 times these values.

Discussion

Control of public health pests in structures and households has emphasized the use of residual insecticides, usually applied from a compressed air sprayer or aerosol in a liquid carrier. When used, pyrethrins are usually aerosolized, sometimes from ultra low volume equipment. The latter techniques exploit the rapid knockdown attribute of the pyrethroids, and minimize problems with photosensitivity by using them in protected (e.g., food handling) environments where persistence is not desirable.

Development of some photostable pyrethroids, applied as spot and crack and crevice sprays for residual deposit, greatly increased their utility to the pest control operator. For example, the formulation of cypermethrin as a wettable powder considerably reduces its breakdown and absorption into the substrate (C.S., unpublished data). In the present test, cypermethrin appeared to provide good control for at least 3 mo, in contrast with the 1–4 wk normally attributed to conventional insecticides.

Sanitation. Based on visual counts with flashlight illumination (Wright 1979) and trapping (Wright & Dupree 1984), a significant positive relationship was established between cockroach numbers and poor sanitation in single-family dwellings. Sherron et al. (1982) corroborated these results in their study of cockroach demography in apartments and showed that number of embryos and number of emerging nymphs per ootheca were not affected by sanitation. However, Owens (1980) and Bertholf (1983) reported that improving of sanitary conditions did not reduce the cockroach population.

I used a modification of Bennett's (1978) sanitary rating scale similar to the above studies and showed a significant positive correlation between poor sanitation and cockroach population density. It is important to note that no attempt was made to modify sanitation and to examine the concomitant change in the cockroach population, nor were sanitary conditions monitored during the study. I assumed that an instantaneous measure of sanitation midway through the study was representative of a dwelling over time. Koehler et al. (1987) reported that adults constituted ca. 30% (their study) or 20% (J. M. Owens, personal communication) of the total population. In my study, adults constituted ca. 50% of the total population comprising ca. 30% males and 20% females (Fig. 3). Moreover, the age-sex composition appeared to remain unchanged under different sanitation levels.

When integrated with insecticides, sanitation has been shown to have a significant impact on their efficacy. Gupta et al. (1973, 1975) concluded that insecticides were more effective in homes with good sanitation. My data support this claim—I have shown that poor sanitation reduced the efficacy of otherwise effective insecticides (e.g., cypermethrin). Moreover, the increase in trap catch over time was significantly higher in control apartments with poor sanitation than in control apartments with good sanitation (Fig. 5). This relationship emphasizes the importance of coordinated efforts by housing authorities, residents and the pest control operator. Although not demonstrated experimentally, improved sanitation should increase the efficacy of insecticide treatments.

Resistance. Based on Jersey City Housing Authority records, the field collected cockroaches have been treated with organochlorines (chlordane), organophosphates (diazinon, malathion, chlorpyrifos), carbamates (propoxur), and pyrethrins. Thus, resistance to cypermethrin may be due to cross-resistance, introduction of resistant cockroaches, selection with pyrethrins, or all of the above. Collins (1975) showed that propoxur selection in the laboratory conferred to *B. germanica* cross-resistance to diazinon, DDT, and pyrethrins. In my study, cockroaches exhibited no resistance to fenvalerate and cyfluthrin (D. Cochran, personal communication), low resistance to diazinon (1.84 times) and chlorpyrifos (1.34 times), moderate resistance (4.51 times) to cypermethrin, and very high levels of resistance to carbamates (>100 times) and pyrethrins (>140 times; D. Cochran, personal communication). Cockroaches were collected at the conclusion of the field study, but selection with cypermethrin did not contribute to the resistance observed because resistance to cypermethrin was consistent across control apartments and apartments treated with any of the three insecticides (Table 3). In other insects, broad cross-resistance to various pyrethroids results from selection with a single pyrethroid or with DDT.

Scott et al. (1986) showed that a DDT-selected strain of the German cockroach (kdr > 280 times) was highly cross-resistant (6.1–31 times) to five pyrethroids when exposed by topical application to the abdomen, head, or legs. However, in a surface contact exposure test, these kdr-resistant cockroaches were only moderately cross-resistant to cypermethrin (1.9–4.0 times) and deltamethrin (1.5–1.8 times). Their findings indicate that, in the case of cypermethrin, the surface contact test in the laboratory is more predictive of the response of the German cockroach to the insecticide in the field.

In my study, the contact test resulted in low resistance (1.34 times) to chlorpyrifos, yet application of chlorpyrifos in the field failed to reduce trap catch. These disparate results indicate that the surface contact test may not be a sensitive test for measuring resistance to chlorpyrifos, that repellency of insecticides may confound trap catch data (see below), or both. Milio et al. (1987) report similar disagreements between results from resistance evaluation in the laboratory and empirical observations of control failures in the field; they conclude that the surface test may be ineffective for detecting organophosphate resistance in the German cockroach.

High resistance to carbamates may also be caused by selection with propoxur, cross-resistance, or both. Carbamate resistance may be due to a desensitized cholinesterase receptor site or to increased rate of detoxification (Casida 1963). The latter may explain why the German cockroach may show resistance to some carbamates and not others. Barson & Renn (1983) reported bendiocarb resistance in field-collected German cockroaches that had never been exposed to bendiocarb; propoxur resistance in these insects was negligible. However, Nelson & Wood (1982) documented high levels of resistance to both materials in field-collected cockroaches, and Collins (1976) showed that a laboratory strain of the German cockroach selected with propoxur for 33 generations was cross-resistant (tested by topical application) to various carbamates, organophosphates (diazinon, malathion, chlorpyrifos), pyrethrins, and DDT; diazinon-selected cockroaches had a similar resistance spectrum. It is important to note that the WHO continuous tarsal contact test was conservative (showed low resistance to propoxur compared with other tests) (Collins 1976), indicating that resistance in all field-collected cockroaches in my study was very high. Indeed, whereas synergism with piperonyl butoxide reduced the LT_{95} value of propoxur-treated susceptible cockroaches, resistance ratios in field-collected cockroaches remained >100 times as great, indicating very high resistance.

Temperature. Type I pyrethroids have a negative temperature coefficient, being more toxic as temperatures decrease. In the honeybee (*Apis mellifera* L.), cypermethrin, a Type II pyrethroid, exhibits a similar relationship with temperature as Type I compounds (Delabie et al., 1985). Conversely, in the cockroach, the toxicities of cypermethrin and deltamethrin are higher at higher temperatures (Scott & Matsumura 1983). The relationship between toxicity and temperature is important in practical pest control, particularly in multiunit housing developments. My study was done throughout the summer months during which temperatures in some apartments were as high as 38°C. On the upper floors of the test building, heat and smoke usually escaped from the central incinerator, increasing the temperature in the hallway and apartments. Moreover, the German cockroach prefers both warm and humid conditions (Cornwell 1968) and is most common in microhabitats which favor such conditions (e.g., cabinet void under sink). Most conventional insecticides and Type I pyrethroids lose efficacy under such conditions. Therefore, although resistance to cypermethrin (4.5 times) was higher than resistance to chlorpyrifos (1.3 times), cypermethrin resulted in greater reductions in trap catch, possibly because of its increased toxicity under these environmental conditions, greater accessibility of a wettable powder than an emulsifiable concentrate, or both.

Repellency. Delabie et al. (1985) found that a commercial formulation of cypermethrin was highly repellent to honeybees principally because of the formulation ingredients, not to cypermethrin itself. Schneider & Bennett (1985) confirmed this finding for cockroaches but also noted that despite the high repellency, consistent high mortality resulted because of the greater toxicity of cypermethrin than that of other insecticides. High toxicity may also explain the higher field efficacy of cypermethrin in my tests, despite its repellency and low to moderate resistance of cockroaches to it.

It is important to recognize that redistribution of insects may also occur for reasons other than the repellent effects of the insecticides. Spatial distribution (e.g., degree of aggregation or dispersion) may be density-dependent (Taylor 1987), resulting in unpredictable changes in both sampling efficiency and variability in trap catch as the population decreases. I have shown that the sex and adult/nymph ratios of sampled cockroaches change little after insecticide application (Fig. 3).

Recently, Koehler et al. (1987) trapped German cockroaches in "low-income apartments" and concluded that "currently available suppression technology appears to have some impact, but falls markedly short of that needed to keep populations suppressed to imperceptible levels." However, numerous papers on control of cockroaches in such apartments report remarkable success with 99% and 100% reductions in trap catches or visual counts which are usually attributed to mortality resulting from insecticide treatment (i.e., insecticide effica-

Table 3. Resistance levels of German cockroaches from different apartments based on the tarsal contact WHO method

Insecticide	Dose ($\mu g/cm^2$)	VPI normal susceptible		Apt. 53[a] cypermethrin			Apt. 57 chlorpyrifos		
		Slope ± SE	LT[c] (95% CL)	Slope ± SE	LT (95% CL)	RR[d]	Slope ± SE	LT (95% CL)	RR
Propoxur	0.41								
LT_{50}		5.26 ± 0.19	30.1 (27.7–32.3)	e	e	>100	e	e	>100
LT_{95}			61.8 (56.8–68.3)	e	e	>100	e	e	>100
Propoxur ± PBO	0.41								
LT_{50}		4.73 ± 0.32	34.0 (28.2–37.5)	na			na		
LT_{95}			47.3 (43.7–60.4)	na			na		
Bendiocarb[f]	3.43	5.12 ± 0.26	38.8 (34.2–43.4)	e	e	>100	e	e	>100
Chlorpyrifos	16.50	11.06 ± 0.09	44.5 (42.8–46.0)	11.60 ± 0.09	58.0 (55.2–60.2)	1.30	7.99 ± 0.13	75.8 (72.5–78.8)	1.70
Cypermethrin	0.26	2.80 ± 0.36	51.0 (44.3–56.8)	2.77 ± 0.36	188 (173–203)	3.69	3.54 ± 0.28	189 (168–207)	3.70
Diazinon[g]	41.10	9.87 ± 0.10	44.9 (42.7–46.8)	na			na		

Insecticide	Dose ($\mu g/cm^2$)	Apt. 98 untreated			Apt. 104 untreated		
		Slope ± SE	LT (95% CL)	RR	Slope ± SE	LT (95% CL)	RR
Propoxur	0.41						
LT_{50}		e	e	>100	e	e	>100
LT_{95}		e	e	>100	e	e	>100
Propoxur + PBO	0.41						
LT_{50}		na			na		
LT_{95}		na			na		
Bendiocarb[f]	3.43	e	e	>100	e	e	>100
Chlorpyrifos	16.50	11.76 ± 0.09	59.5 (57.1–61.7)	1.34	11.76 ± 0.08	56.1 (54.2–57.8)	1.26
Cypermethrin	0.26	4.40 ± 0.23	204 (190–217)	5.57	3.21 ± 0.31	251 (227–273)	4.92
Diazinon[g]	41.10	na			na		

Insecticide	Dose ($\mu g/cm^2$)	Apt. 107 propoxur			Mean RR			Maryon Gardens[b] untreated		
		Slope ± SE	LT (95% CL)	RR	Slope ± SE	LT (95% CL)	RR	Slope ± SE	LT (95% CL)	RR
Propoxur	0.41									
LT_{50}		e	e	>100			>100	e	e	>100
LT_{95}		e	e	>100			>100	e	e	>100
Propoxur + PBO	0.41									
LT_{50}		e	e	>100			na	e	e	>100
LT_{95}		e	e	>100			na	e	e	>100

Table 3. Continued

Insecticide	Dose ($\mu g/cm^2$)	Apt. 107 propoxur Slope ± SE	Apt. 107 propoxur LT (95% CL)	Apt. 107 propoxur RR	Mean RR Slope ± SE	Mean RR LT (95% CL)	Mean RR RR	Maryon Gardens[b] untreated Slope ± SE	Maryon Gardens[b] untreated LT (95% CL)	Maryon Gardens[b] untreated RR
Bendiocarb[f]	3.43	[e]	[e]	>100			>100	[e]	[e]	>100
Chlorpyrifos	16.50	12.57 ± 0.08	47.9 (46.1–49.4)	1.08			1.34	6.28 ± 0.16	70.0 (64.8–74.5)	1.57
Cypermethrin	0.26	2.26 ± 0.44	239 (213–266)	4.69			4.51	na		
Diazinon[g]	41.10	na			6.61 ± 0.15	82.7 (77.9–87.1)	1.84	na		

[a] Treatment is listed next to apartment number. N, 60 for all treatments.
[b] Maryon Gardens is an apartment complex located 5 km from the study site and operated by the same housing authority.
[c] All LT values are min.
[d] RR is resistance ratio: LT_{50} or LT_{95} of field collected strain divided by LT_{50} or LT_{95}, respectively, of VPI normal strain.
[e] Trials were suspended when RR exceeded 100.
[f] Where not otherwise indicated, LT_{50} is reported.
[g] Diazinon resistance was tested on a pool of cockroaches from all apartments.

cy), and equated with "population reduction." Although such observations and those of Koehler et al. (1987) appear contradictory, they may in fact represent different assessments of similar results. Relative inefficiency of traps and repellency of insecticides may result in seemingly large reductions in the population when compared with trap counts before treatment. Thus, an "imperceptible level" (Koehler et al. 1987) may not be attained even with reports of 95–100% reduction in the population. My study highlights the importance of untreated control apartments in such studies. Even treatments which resulted in statistically significant reductions in trapped cockroaches left significant nuclei of cockroaches for future outbreaks; they most certainly did not accomplish an "imperceptible level" of cockroaches. Yet, such seemingly ineffective treatments would result in significant reductions in cockroaches when compared with ca. 500% increases in untreated controls. These reductions, though unimpressive in light of the reproductive potential of the remaining cockroaches, are nonetheless significant in health-related pest management. Therefore, density-dependent effects such as the allergenic impact of cockroaches and associated organisms (Kang & Chang 1985) may be significantly reduced in treated apartments compared with untreated apartments.

These observations indicate that an important component of assessments of management techniques may be comparison of trap catch in treated apartments with that in untreated apartments. Another reason for the inclusion of controls in studies of insecticide efficacy is that, in some cases, the control treatment may be more effective than an insecticide, although reductions in trap catch may occur in both (Taylor 1987). Of course, a criticism of this approach is that trap catch in untreated apartments will increase artificially (see Fig. 1) as repellent insecticides stimulate movement between apartments, and that it may not be practical to request that residents accept the large cockroach populations associated with untreated control apartments.

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