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CONTROL OF AMERICAN COCKROACHES (DICTYOPTERA: BLATTIDAE) IN SEWER SYSTEMS

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Abstract American cockroaches, *Periplaneta americana* (L.), left undisturbed, often develop to enormous numbers and become major pests in sanitary sewers throughout much of the world. They are also domiciliary pests in many places, especially in southeast Asia. Moving from sewers, they often invade surrounding streets and buildings, and have been implicated as being associated with allergy and disease. They are particularly troublesome in metropolitan areas where manhole maintenance is neglected for long periods. As the use of chlorpyrifos and diazinon for cockroach control has been discontinued in many parts of the world, municipalities are seeking to use approved IPM strategies and only materials with low mammalian toxicity and minimal environmental impact. Various sprays, dusts and baits registered in the U.S. are used to control *P. americana*, but there is little evidence as to their efficacy in sewers.

Neonicotinyl baits provide rapid, effective and relatively inexpensive control of American cockroaches in sewers. Both fipronil, 0.05% gel bait (MaxForce FC Roach Killer) and imidacloprid, 2.15% gel bait (Pre-Empt, IMAGEL) provided 96 to 99% control for 6 months or longer. Treating adjacent manholes whether they contained cockroaches or not broadened the sphere of effect, probably by reducing the likelihood of cockroaches using adjacent untreated holes as refuge. Effective treatment consisted of applying the gel as a narrow band circumscribed just below the cover, not deep within. Gel bait dispensed from cards or solid and granular baits dispensed from devices lower in the manholes were not as effective. Although covered with fungus, gel baits retrieved from manholes months later remained toxic, suggesting prolonged efficacy against nymphs which subsequently emerge. Resurgence of populations in some manholes appears to occur as a result of all the bait having been consumed rather than from degradation of AI. Fipronil, 0.01% gel bait provided only 40 to 50% control, suggesting that the 0.05% rate is near the lower limit of its performance. A similar rate-dependency is likely for imidacloprid. As little as 50-100 g/manhole of a proprietary dust consisting of 2.0% pyrethrins, 10.0% piperonyl butoxide, 35.5 % boric acid, and 50% diatomaceous earth blown into the system with a commercial DeVilbis sprayer provided > 98% control for at least 3 months. The advantage of this technique was that lateral lines and adjacent manholes could be treated. This technique did, however, require specialized equipment.

Release of up to 800 per manhole of the parasitoid *Aprostocetus hagenowii* (Raxeburg) had no measurable effect on cockroach populations. This parasite is reportedly effective on *P. americana* and the smokybrown cockroach, *P. fuliginosa*, in other areas, but its lack of effectiveness here suggests that the sewer environment may be inappropriate for this insect.
Key Words *Aprostocetus hagenowii*, fipronil gel bait, imidacloprid gel bait, cockroach control, *Periplaneta americana*, sewers

INTRODUCTION

The American cockroach, *Periplaneta americana* (L.), frequently infests sewers, steam tunnels and drainage systems throughout the world. It is an important pest throughout Southeast Asia (Lee and Lee, 2000) and it is the predominate species found in sewers in the United States (Ebeling, 1975; Story, 1990). American cockroaches may breed to enormous numbers in these protected places and besides being a nuisance, they often move from sewers into commercial establishments and dwellings where they contaminate items with their saliva and excrement (Eads et. al., 1954; Mackie, 1969). They are potential mechanical vectors of disease (Lee, 1997) and may infrequently cause allergic and asthmatic responses among sensitized individuals (Brenner et. al., 1991; Lee, 1997). At least 22 species of pathogenic bacteria, virus, fungi, and protozoans and 5 species of helminthic worms have been isolated from field-collected *P. americana* (Roth and Willis, 1960). Okafur (1981) cultured *Canadida albicans*, *Escherichia coli*, and *Salmonella typhimurium* from *P. americana* collected from kitchens and toilets. Psittacine birds such as cockatoos may acquire a fatal disease, *Sarcocystis falcatula*, from feeding on infected *P. americana*. The tendency of cockroaches to venture from unsanitary places such as sewers presents a potential risk to nearby facilities.

Movement of cockroaches out of infested sewers is seasonal and probably related to temperature and the density of cockroach population. Moderate temperatures are more conducive to cockroach movement from sewers than are either low or high temperatures. Jackson and Maier (1955; 1961) reported that in the desert

community of Phoenix, Arizona, about 6% of cockroaches they tagged in August (hot) or January (cool) could be recovered up to 350 yards from their sewer release site, but the number caught in June (moderate) was consistently much greater. Cockroaches tend to leave the manholes during the evening. The number of oothecae, and thus the resultant number of cockroaches present, may increase seasonally in relation to the number of adults present, there being the greatest number of oothecae in the spring (Bao and Robinson, 1988). Confirming a relationship between numbers of cockroaches present and their movement from manholes, Rust et. al. (1991) found about 60% of the population in sewers were adults in June, but that this number decreased to about 25% in the winter. Mackie (1969) found that at certain times of year, cockroaches emerged from manholes and infested nearby buildings. Of the 271 food-handling establishments Mackie (1969) inspected, 40 (15%) had American cockroaches and he typically found mostly large nymphs and adults, suggesting the *P. americana* had moved to the establishments from the sewers. Regardless of time of year, controlling cockroaches in sewers decreases infestations in adjacent buildings (Roth and Willis, 1960).

American cockroaches inhabiting sewerage system in large numbers have been an ongoing problem for municipalities worldwide. Concerns over maintenance worker safety and public health issues arising from the invasion of commercial and residential establishments by these pests have prompted efforts to suppress or eradicate them at their point of origin. Recommendations for control have included repeated thermal fogging with synergized bioresmethrin (Chadwick and Shaw, 1974; Chadwick et. al., 1977) or dusting with Drione® (a combination of amorphous silica gel and synergized pyrethrins) or boric acid technical dust (Rust et. al., 1991). Chlorpyrifos and avermectin were found to be repellent to American cockroaches, but baits containing hydramethylnon or sulfluramid provided best results (Smith and Appel, 1996). Large American cockroaches would not feed on bait in stations, thereby precluding the use of stations as delivery systems in sewers and the presence of competitive food reduced bait efficacy (Barlow and Robinson, 1977). Deltamethrin, imiprothrin, and d-phenothrin have also been used in sewers for cockroach control, but they have provided less than satisfactory levels of control. Sprays and dusts contaminate the surface of manholes so that it is unsafe for maintenance personnel to enter them or contaminates sewer effluent either by drift or by dripping down the walls of the manholes. Such contamination is unacceptable to many municipalities because of public concern, potential worker liability, possible interference with sewage treatment microorganisms, and contamination of sewer system outfalls.

The oothecae of *P. americana* are susceptible to parasitism. The oothecae incubate 4 to 7 weeks, usually partly concealed in a crack or crevice or fully exposed. There are several hymenopterous parasitoids of American cockroaches, among the most prominent of which is *Aprostocetus (Tetrastichus) hagenowii* (Raxeburg) (Lebeck, 1991). Cameron (1955) reported that *A. hagenowii* is a more effective control organism than other parasitoid species because it is gregarious, has a short developmental time (24 - 40 days), and develops even if the oothecae are disrupted. It does not have a preference of attacking oothecae of a specific age (Kumarasinghe and Edririsinghe, 1987). It is a hearty wasp, living in the laboratory an average of 7.3 days if fed honey water, and 3.4 days if starved (Edmunds, 1955). About 20% of *P. americana* in Texas (Piper et. al., 1978) and 16% of *P. americana* from domiciles in Sri Lanka (Narasimham and Sankaran, 1979) were parasitized by *A. hagenowii*. When Hagenbuch et. al. (1989) released *A. hagenowii* 3 times a week for 5 weeks into chambers containing *P. americana*, they achieved 98% parasitization and wasp development, indicating the potential for sustaining a population of wasps. Studies with this and other cockroach parasitoids (Coler et. al., 1984) that effectiveness may be limited, however, to high densities of cockroaches. Thus, augmentative or inundative release of parasitoids may be necessary to suppress populations of cockroaches (Slater et. al., 1980).

The objective of this study was to develop a simple cost-effective IPM biorational approach for controlling American cockroaches in sewers, with an emphasis on integrating baits and parasites. The intent was to suppress cockroach populations while simultaneously reducing the amount of pesticide applied. We assumed application of relatively small amounts of non-volatile bait to discrete, predictable sites would eliminate pesticide exposure to maintenance personnel and reduce the likelihood of contaminating sewer effluent.

MATERIALS AND METHODS

Sites. Reported here are 3 chronologically overlapping studies conducted in two communities in southern California. Studies were made with a parasitic wasp biocontrol agent, a proprietary dust, and what at the time were proprietary gel baits. Studies began in Santa Monica in 1999 and in Riverside in 2003. The study in Santa Monica involved baits and parasitoids and the study in Riverside involved only baits. The Santa Monica Study has been discontinued, but the study in Riverside continues in 2005.

Sewers systems were visually inspected before and after treatment. The City of Santa Monica, CA is a coastal community of 85,000 residents, about 24 km (15 miles) west of Los Angeles civic center. Riverside is a city of 170,000 residents, about 97 km (60 miles) east of Los Angeles. Riverside is the warmer of the two cities where this work was done, being located in the transition zone between the Los Angeles basin and the western margin of the Colorado Desert. To assure that representation of the city was included, sewers in 3 divergent areas of Santa Monica were inspected for cockroach activity by city sewer maintenance personnel. These areas included the restaurant district, a residential district, and areas near the beach. Each district was about 2 to 3 miles from one another. Only manholes in which there were > 50 cockroaches were included in the study, as were only manholes with intact built-in metal rung ladders and brick or masonry construction. Manholes for study in Riverside were systematically arranged along sewer lines surrounding the central downtown Natural History Museum and adjacent areas. Museum staff complained about finding American cockroaches in museum hallways, and we documented cockroach presence with sticky traps. Sewer maintenance personnel from each city assisted by directing traffic and removing the heavy metal covers from the manholes.

Counts of cockroaches were made during the day. A high-intensity DC seal beam lantern or a 6 by 8 in mirror was used to reflect sunlight so that the number of cockroaches in them could be counted. The number of cockroaches per manhole was counted and recorded except when estimations were made when there were so many cockroaches (usually > 500) that they could not be counted individually.

Dust. A proprietary dust formulation consisting of synergized pyrethrins, 35% boric acid, and 50% diatomaceous earth was provided along with the equipment to apply the dust by the manufacturer (Environmental Products & Technologies Corp, Westlake Village, CA). We were particularly interested in the dust because the manufacturer claimed that 50 to 100 g doses of the dust may be effective. Rates > 1 to 2 pounds (454 to 908 g) per manhole are usually needed for Drione® or technical boric acid (Rust et. al., 1991). Dust efficacy was evaluated in 10 infested manholes only in Santa Monica. Pre-weighed packets of the dust were applied with a DeVilbis airless paint gun connected with a 40 ft high pressure hose to a 30 gal air compressor. For treatment, the manhole cover was removed and a 4 by 4 ft piece of $^1/_2$ in plywood with a 1-1/4 in hole drilled through its center was set directly over the manhole. The dust in the spray gun reservoir was then emptied at 60 psi pressure into the system through the hole in the plywood. The plywood was left in place for about 3 minutes to allow the dust to settle, after which the metal cover was replaced on the manhole. Ten untreated infested manholes were used as comparison. Counts of the number of cockroaches per manhole were made approximately monthly for up to 3 months post-baiting.

Parasitoids. We evaluated the efficacy of *A. hagenowii* as a biocontrol agent in sewers. Developing *A. hagenowii* parasitoids were purchased from a commercial insectary as immatures in parasitized *P. americana* oothecae (PNE, Inc., North Ridgeville, OH). Two intense releases were made, one on 31 March and another on 24 June. Thirty *P. americana* oothecae in which *A. hagenowii* had oviposited 14 days before were suspended in each of 15 manholes determined to each contain at least 50 adult *P. americana*. Treatments consisted of *A. hagenowii* alone or in combination with fipronil and imidacloprid bait. It was assumed that bait in the manhole would not affect the wasps. One cage of 30 parasitized oothecae was stapled to a nearby telephone pole to determine if the parasitoids would emerge under outdoor ambient conditions. In addition, for each release batch, 3 lots of 30 (n = 90) parasitized oothecae were maintained in a screened cage at 26˚C in a growth chamber in the laboratory to determine emergence rate. A parasitized ootheca reportedly supports 30 to 35 developing *A. hagenowii*, about 90% of which emerge as adult wasps. The wasps were placed in the selected manholes in Santa Monica within days of being received. They were allowed to emerge in the manholes in 5 by 6-cm screen bags made of flexible 18-mesh fiberglass window screen prepared with the oothecae inside. The bags were made by folding a 10 x 12 cm piece of screen onto itself and stapling the edges closed. The bags were placed inside 8 x 5 x 3 cm hardware cloth cages and suspended by a 0.5-m piece of stainless steel wire from a ladder rung near the top of the manhole. The hardware cloth cages protected the oothecae from rodents. The cages and parasitized oothecae were left in the manholes for 21 days at which time they were returned to the laboratory. The same procedure was done with a fresh batch of parasitized oothecae at 30 days.

The retrieved oothecae from the manholes were kept at 25˚C and 50% RH in 2.5-dram plastic vials that had a piece of Kimwipe® (Kimberly-Clark Corp., Atlanta, GA) over the open end held in place with a snap lid with small holes to allow air exchange. The oothecae were checked daily and the number of cockroaches or parasitoids that emerged was counted.

Sentinel oothecae from a laboratory culture of *P. americana* were used to determine natural parasitzation rate in manholes and the surrounding area. Aliquots of ten 14-day-old oothecae were placed in wire mesh

cages in treated and control manholes and on telephone poles around the city. The sentinel oothecae were left in place about 6 months at which time they were returned to the laboratory for examination.

Baits. Commercial and proprietary baits were evaluated in the laboratory as to their palatability and efficacy against adult *P. americana*. Five mm and five f f cockroaches were placed in covered 3.8-l glass jars provisioned with water, dog chow and corrugated cardboard harborage. The cockroaches were allowed to acclimate in the jars for 7 days at which time about 5 g test bait was presented ad libitum. Three replicates (n = 15) were used for each kind of bait tested. The baits tested included solid, granular, and gel baits. Solid and granular baits were provided by The Clorox Corp., Clorox Technical Center, Pleasanton CA. The solid bait included fipronil 0.01% and 0.001% and hydramethylnon 1.0% and 2.0% solid disks. Granular baits included fipronil, 0.003% fire ant bait and two hydramethylnon, 1.65% ant baits (MaxForce FG and MaxForce G Professional Granular Insect Control). The number of dead cockroaches in each jar was counted and removed daily. (Note: the companies that provided the baits for testing have since merged or changed name, and the ingredients and trade names of the baits have also correspondingly changed). Fipronil, 0.01% gel bait (Max Force; Imagel) and imidacloprid, 2.15% gel bait (Pre-Empt) for the Riverside study were provided by Bayer CropSciences, Kansas City, MO.

Bait in manholes was typically covered with fungus within about 3 weeks. Moldy bait from manholes was bioassayed. It was thought that moldy bait might be unpalatable to cockroaches or that high humidity that encourages fungal growth might also hydrolyze bait actives, thereby rendering the bait relatively inactive. The activity of moldy bait from manholes was compared with bait kept at 100% humidity in a closed container for 3 weeks in the laboratory. About 5 g of each of the test bait was placed in 3.8-l glass jars set up as above with 10 adult American cockroaches. The number of dead cockroaches were counted and removed approximately daily from each jar for up to 1 month.

Various bait dispenser configurations were tested, but the City of Santa Monica would not allow devices to be lowered to the floor of the manholes because that might contribute to blocking waste flow. Stations had to be suspended from the metal ladder rungs. We observed that American cockroaches avoid or are reluctant to negotiate nearly any bait station device. Most manholes in Riverside either had no metal rungs and city policy was that no objects could be lowered into or suspended in their manholes on a permanent basis. Therefore, the only bait system we could evaluate other than free-standing bait was a gel bait card in Santa Monica. The cards consisted of a 15 by 12-cm plastic card onto one side of which was glued a 13 by 10 cm piece of 1.25 cm thick evaporative cooler pad. A 3 by 3-cm piece of Velcro adhesive fabric was cemented to the other side and the corresponding attachment fabric was cemented to the wall of the manhole. This provided a secure attachment for the card in the manhole. For use, gel bait was thoroughly spread liberally into the cooler pad and it was affixed to the wall of the manhole. The cooler pad kept the bait in pace and prevented it from dripping.

Field Efficacy of Gel Baits and Parasitoids. Gel baits are excellent pest management (IPM) tools, mostly because they satisfy safety and efficacy criteria. They are non-volatile, long-lasting, and are effective against many species of cockroaches at low concentrations of active ingredient. They are easy to transport and apply and, when used as directed, remain where they have been applied, drift, spillage, and contamination of non-target areas not being a factor. The efficacy of fipronil and imidacloprid gel baits was evaluated in infested sewer manholes in Santa Monica and Riverside. Trials in Santa Monica began in June 1999 and trials in Riverside began in August 2003. Treatment was randomly assigned to manholes visually counted for cockroaches and which contained at least 50 cockroaches. Because results in Santa Monica indicated that cockroaches move through lateral connecting lines to adacent manholes, treatment in Riverside consisted of also treating adjacent manholes whether they contained cockroaches or not. For treatment, the manhole cover was removed and a single complete circle of the contents of one syringe load 30 g of bait was enscribed 5 cm below the opening of the manhole. This complete line of bait ensured that cockroaches encountered bait if they tried to leave the manhole through the top. This was a treatment that maintenance personnel or commercial pest control operators could easily make. Retreatment was made at the time of post-treatment counts if most of the bait had been consumed.

Santa Monica and Riverside administrators were enthusiastic about the possibility of obtaining cockroach control with parasitoids. This also appeared to be an excellent IPM tool. Bags of 30-33 *P. americana* oothecae parasitized by *A. hagenowii* were suspended on regular schedule in infested manholes as described above. Efficacy over time was determined for treatment with gel bait alone, parasitoids alone, and gel bait + parasitoids. Obviously, a dust + parasitoid combination was not evaluated because it is likely that surface contamination by the dust would adversely affect the wasps.

Efficacy was calculated from the visual counts of cockroaches in the manholes made periodically for up to several months afterwards. The total number of cockroaches per treatment was grouped. For any given treatment, overall percent control (% C) = $[C_i - C_t / C_i] \times 100$, where C_i is the total original number of cockroaches and C_t is the total number of cockroaches at time t.

RESULTS

Dust

Excellent control of American cockroaches in sewers was accomplished with as little as 50 g EPT pyrethrins-boric acid dust per manhole. Greater than 95% control was attained within a month in all treated manholes, the average number of cockroaches per manhole being reduced to near zero from 150 to 220 cockroaches (Table 1). There was no apparent resurgence of cockroaches within 4-months. Because of changing personell in Santa Monica, we did not continue the study of the dust. The advantage of the dusting technique was that the dust was apparently forced into lateral sewer lines where it affected cockroaches. Because the study with the dust did not continue past 3 months, it is unclear if emerging nymphs were affected. Dusting with small amounts of EPT dust was highly effective but required electric power, and bulky specialized equipment.

Table 1. Performance of baits, a parasitoid (*A. hagenowii*), and a boric acid dust against the American cockroach, *P. americana*, in sewer manholes in Santa Monica, California (USA).

			% Reduction at indicated week[a]					
Treatment[b]	Parasitoid[c]	Avg. before	3	6	9	12	15	18
Fipronil gel	No	292	29.2	60.2	46.3	70.6	85.0	83.1
"	Yes	147	70.0	20.0	49.5	92.9	79.4	75.7
Imidacloprid gel	No	269	6.1	43.3	29.4	56.2	76.1	87.2
"	Yes	156	55.0	28.8	64.9	89.6	92.6	92.6
No bait	Yes	133	20.9	0.0	0.0	0.0	0.0	0.0
EPT, 50g dust[d]	No	213	99.5	NC[e]	99.5	99.1[f]		
EPT, 100g dust	No	153	100	NC	99.3	98.0		
Untreated	No	168	0.0	0.0	0.0	0.0	0.0	0.0

[a] Average number cockroaches before and after based on visual counts.
[b] Five manholes per treatment. Bait on bait cards.
[c] Innundative release 31 March 1999.
[d] Rate per manhole. EPT dust = pyrethrins, 2.0%; piperonyl butoxide, 10.0%; boric acid, 35.5%; diatomaceous earth, 50.0%.
[e] NC = not counted. f Both dust series discontined at 12 weeks

Parasitoids

Retrieved sentinel oothecae were examined microscopically, and none of > 1000 of them were stung by any egg capsule parasitoid. Based on these data, there is a strong probability that there are few, if any, cockroach parasitoids were established in Santa Monica. This is interesting, especially considering their prevalence in the southeastern United States.

Of the parasitized oothecae placed in the sewers on 31 March, adult wasps emerged from only 23% compared with 97.7% in the laboratory. The corresponding numbers for the June batch were 86.7% and 93.3%, respectively. Environmental condition may have been sufficiently different in March compared to June to account for the lower emergence rate in March. There was no reduction in the number of American cockroaches in manholes treated with the parasitoid alone. Reductions that occurred with *A. hagenowii* plus bait were attributable to the bait. Results from the first release of parasitoids are shown in Table 1. There was no reduction in the number of cockroaches present. Although not shown in table, efficacy did not improve after the second release.

Activity of Baits

Of the baits tested in the laboratory, 0.01% fipronil solid bait disks provided fastest kill of American cockroaches (Table 2). This is consistent with Kaakeh et al. (1997) that bait containing 0.05% fipronil provided more rapid kill (LT) of American cockroaches than bait containing either 0.53% chlorpyrifos or 1.65% hydramethylnon. The efficacy of bait containing fipronil was apparently rate-dependent, bait containing 0.001% fipronil providing only 67 to 80% mortality within 28 days, whereas bait containing 0.003% fipronil provided 80 to 88% mortality by 7 days and 100% mortality by day 21. When *P. americana* are provided alternative food sources, bait consumption was slow and some adults lived 28 days. This suggests that other available food may affect ultimate levels of control by bait alone.

Table 2. Mortality of adult American cockroaches presented bait ad libitum along with competitive food.

			% Dead at day[a]					
Bait, % ai	Form	Sex	1	3	7	14	21	28
Fipronil, 0.001	Solid	Male	0.0	0.0	60.0b	80.0ab	80.0b	80.0b
		Female	0.0	0.0	13.3d	40.0c	66.7bc	66.7b
Fipronil, 0.01	Solid	Male	86.7a	100a				
		Female	86.7a	100a				
Hydramethylnon, 1.0	Solid	Male	0.0	0.0	60.0b	80.0ab	80.0b	80.0b
		Female	0.0	0.0	13.3d	40.0c	66.7bc	66.7b
Hydramethylnon, 2.0	Solid	Male	0.0	0.0	53.3b	100a		
		Female	0.0	0.0	46.7b	100a		
Fipronil, 0.003	Granule	Male	0.0	60.0b	80.0a	93.3a	100a	
		Female	0.0	52.9b	88.2a	94.1a	100a	
Hydramethylnon, 1.65	Granule	Male	0.0	0.0	18.8cd	62.5ab	81.2b	100a
	(FG)	Female	0.0	0.0	21.4cd	78.6ab	92.9a	100a
Hydramethylnon, 1.65	Granule	Male	12.5c	12.5c	25.0c	93.8a	100a	
	(G)	Female	0.0	0.0	31.2c	100a		
Fipronil, 0.01	Gel	Male	13.3c	60.0b	66.7ab	80.0	100a	
		Female	26.7bc	93.3a	93.3a	100		
Imidacloprid, 2.15	Gel	Male	66.7b	73.3ab	86.7a	86.7	86.7ab	86.7
		Female	40.0bc	66.7ab	66.7ab	80.0	86.7ab	86.7
Untreated	-	Male	0.0	0.0	0.0	0.0	0.0	0.0
		Female	0.0	0.0	0.0	0.0	0.0	0.0

Within a column, values followed by same letter are not significantly different (ANOVA, $P > 0.05$)

[a] For each bait, 3 replicates of 5 male + 5 female (n = 30) *P. americana.* Dead cockroaches removed daily.

Solid bait could not be adequately affixed to bait cards. Cockroaches ate solid bait particles or granules glued with water-soluble glue (Elmer's Multi-Purpose Glue, Elmer's Products, Inc., Columbus, OH) to bait cards, but they could not dislodge particles fastened to the card with epoxy cement. With water-soluble glue, some particles dislodged in high humidity and would probably fall into the waste effluent. Gel baits provided significantly slower kill in the laboratory, but because they provided reasonably rapid effects and remained fastened and available on the cards or surfaces to which they were applied for the duration of the study, gels appeared to be the best formulation for sewers.

Counts were made in Santa Monica ~ monthly. The bait was typically covered with fungus, but fresh bait held in the laboratory at 100% humidity did not become moldy. The source of the mold was clearly the sewer rather than the bait matrix. Moldy baits retrieved from the sewers provided about the same speed of activity against cockroaches as did fresh bait. In other words, mold on the bait did not consistently reduce efficacy (Table 3).

Table 3. Efficacy of fipronil, 0.01% and imidacloprid, 2.15% gel baits against American cockroaches in sewers in Riverside, California (USA).

		% Reduction at month[a]			
Treatment[b]	Avg. before	3	6	9	12
Fipronil, 0.01% gel	67	97.0	13.4	25.4	17.9
Imidacloprid, 2.15% gel	96	98.6	100	91.7	90.6
Untreated	153	0.0	0.0	0.0	0.0

[a] Average number cockroaches in 8 manholes before and after. Reductions based on visual counts.
[b] Manholes first baited September 2003 and re-baited if no bait remained at time of counting.

Baiting in Santa Monica was easy and efficacious, and the effect obtained was attributable to bait rather than the parasitoid (Table 1). Reductions with gel bait were significant, but delayed. For instance, reductions at week 6 ranged from 20 to 60%, but were 76 to 93% at week 15. This slow activity is illustrated by 38.1% average control at week 6; 77.3% at week 12; and 84.7% at week 21. In no instance were the cockroaches completely eliminated, the greatest reduction being 92.9% control in one series at week 12. The bait cards were effective, but a single point-source for dispensing bait may limit efficacy, some cockroaches apparently neglecting the card, especially when the bait dries. Emerging nymphs that do not feed on the bait may be an important source of 'reinfestation,' rather than emigration of cockroaches from adjacent manholes.

Counts were made every 3 mos in the Riverside study. Little bait per manhole remained when counts were made and the baits did not have mold develop on them, suggesting that these baits may have contained an effective mold inhibitor. It is more likely that the ingredients are different rather than the sewer environments being significantly different between the cities. Sewers in both localities are warm and damp. Table 3 shows the effects obtained from baiting the Riverside sewers. Imidacloprid bait provided very good results but 0.01% fipronil did not. It is evident that 0.01% fipronil gel bait is about at the lower level of effective concentration.

DISCUSSION

American cockroaches are a serious pest in sewer systems through much of the world. Power dusting with small amounts of pyrethrins-boric acid dust can be highly efficacious, but requires bulky specialized equipment. Baiting is particularly simple and effective if bait palatable to the cockroaches contains sufficient active ingredient to provide kill. The difference in the results we obtained with fipronil bait in Santa Monica and Riverside appear to be related to the amount of active ingredient the bait contained. Fipronil, 0.1% provided

good control but 0.01% did not. Imidacloprid, 2.15% provided very good control, but it is likely that the concentration of active ingredient in the imidacloprid bait could be reduced without reducing control.

Although baits in sewers may become moldy within about 3 weeks, American cockroaches will feed on moldy baits and die. Cockroaches do not seem to be repelled by the mold. The most serious detriment to control with baits appears to be insufficient bait. A small amount of bait enscribed completely around the mouth of a manhole is sufficient to provide good control, provided the bait is insecticidally active. However, reinfestation of manholes appears to be related to the bait being depleted before all the cockroaches have an opportunity to feed on bait. Replenishing bait if it has been consumed or removed is recommended.

Although the parasitoid *A. hagenowii* is reportedly effective against cockroaches elsewhere, our experience in Santa Monica was that even intensive innundative release of this parasitoid in manholes was ineffectual. Perhaps the sewer environment affected their efficacy. We suspect that a factor such as the presence of certain sewer gases may adversely affect parasitoid effectiveness. We have found, for example, that the sewers in which this work was done never have Oriental cockroaches, *Blatta orientalis*, in them although many of the water meter boxes immediately adjacent do contain that species.

Baiting with gel bait containing 0.1% fipronil or imidacloprid, 2.15% gel bait was the easiest and most effective pest management strategy that we examined for control of the American cockroach in sewers in southern California. It is likely that such a simple system would be effective in all parts of the world.

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