A NOVEL TECHNIQUE FOR THE ELIMINATION OF POPULATIONS OF THE ORIENTAL COCKROACH, *BLATTA ORIENTALIS* L. (DICTYOPTERA: BLATTIDAE) USING (S)-HYDROPRENE DELIVERED FROM SIMPLE POINT SOURCES

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Abstract: Two mixed-age (semi-natural) populations of the Oriental cockroach *Blatta orientalis* were established in identical artificial domestic environments contained in steel freight containers. Each population was allowed a 10 week period of acclimation, during which the populations were monitored using Roatel traps. Subsequently, one population was treated with two point sources (filter papers) impregnated with 750mg of the insect juvenile hormone analogue *S*-hydroprene and 150mg of the anti-oxidant butylated hydroxy toluene (BHT). The other (control) population was exposed to point sources impregnated with BHT only. Each source was suspended from the ceiling under a cockroach-proof guard to ensure that physical contact with cockroaches could not occur. Treatments were repeated at six monthly intervals throughout the experiment. Changes in these populations were monitored for approximately two years by trapping every two weeks with live catch Roatel traps. On each occasion, trapped cockroaches were counted, the sexes of adults determined, and adults were examined for external deformities. Trapped nymphs were assigned to 1 of 3 arbitrary size catagories (small, medium or large). Subsequently all trapped insects were released back into their respective containers. In addition, at monthly intervals, 20 adult females were randomly selected from the trapped insects and confined with several trapped males until ten oothecae had been produced. The viability and numbers of nymphs emerging from these oothecae was recorded.

During the first 5 months of the experiment both populations showed a general increase. Subsequently, the control population increased substantially and then remained high for the duration of the experiment. After an initial small increase, the population in the hydroprene treated environment gradually declined and was eliminated after approximately 30 months. In the hydroprene treated container the percentage of adults exhibiting deformities exeeded 90% after 10 months and ootheca production was halted in this population at the same time. This inhibition of reproduction resulted in the eventual eradication of the population. These results suggest that hydroprene point sources could provide an extremely simple, and effective control technique for cockroaches infesting hospital, industrial, food manufacturing and domestic premises.

Key words. *Blatta orientalis*, cockroach, juvenile hormone analogue, hydroprene.

INTRODUCTION

Probably the most frequently encountered pests of public health importance in hospitals, kitchens and other domestic premises, cockroaches are known to carry a wide range of bacteria and other pathogenic organisms (Roth and Willis, 1957; Burgess and Chetwyn, 1979). Of the two most common cockroach pests in the United Kingdom, the Oriental cockroach, *Blatta orientalis* is the predominant cockroach species in hospitals, food factories and institutional buildings. In a recent survey of 220 hospitals undertaken by the U.K Department of Health, 63% were infested with *B.orientalis*, while only 6% were infested with the german cockroach (Baker, 1990). The German cockroach *Blattella germanica* probably occurs more frequently in apartment blocks and hotel or restaurant kitchens where temperatures are generally higher.

The presence of cockroaches in domestic environments can give rise to serious allergic reactions, including athsma, in a substantial proportion of the allergen-sensitive population (Bernton and Brown, 1964; Bernton *et al.*, 1972; Berns, 1987). As well as having the ability to transmit disease organisms, cockroaches foul foodstuffs, equipment and packaging, leaving unpleasant odours in areas that they inhabit. Moreover, the mere presense of cockroaches may cause revulsion and great distress in people whose homes are infested. The public health significance of cockroach infestations in hospitals has been further highlighted in recent years by the lifting of Crown Immunity and the resultant prosecution of a number of Health Authorities under the Food Act.

Existing cockroach control strategies using conventional insecticide spray treatments often fail to give complete or lasting control of cockroach infestations. This may, in part, be due to factors such as the high cost of thorough treatments or because of poor application of pesticides. In addition, the

Proceedings of the First International Conference on Urban Pests.
K.B. Wildey and Wm H.Robinson (editors). 1993

sheer size and complexity of buildings like large hospitals and high-rise estates may make adequate treatment with conventional methods almost impossible.

Some aspects of the biology of *B.orientalis* may also make this cockroach more difficult to control than other species. For example, the oothecae of *B.orientalis* are dropped by the female as soon as they are formed. Often, these oothecae are deposited in locations that are inaccessible or difficult to treat with insecticide sprays or dusts. Furthermore, the long incubation period of oothecae (up to 3 months in cold situations) may allow hatching nymphs to develop unrestrained since previously applied insecticidal treatments may have become degraded or have been cleaned away during this time. In addition, unlike the other pest cockroaches, *B.orientalis* is able to survive outside heated buildings even during the winter months (Beatson and Dripps, 1972). Such populations are unable to produce viable oothecae at temperatures below 10°C (Short and Edwards, 1991) and incubating oothecae are not capable of surviving U.K. winter temperatures (J. Short, unpublished results). However, nymphs and adults are capable of reinfesting indoor areas that have been cleared of cockroaches. These factors, combined with their nocturnal habits, their tendency to hide in deep cracks and crevises, and their ability to migrate temporarily to untreated habitats, including outdoors, have made *B.orientalis* one of the most difficult public health pests to control. In the past, control measures have relied largely on the use of persistent insecticides or on repeated applications of insecticide to deal with nymphs hatching from oothecae and with reinvasion of the premises from outside. Moreover, many current cockroach control programmes are aimed at reducing the population to acceptable levels, and maintaining this by repeated insecticidal treatments. However, in many situations, even small populations are intolerable and the repeated application of conventional insecticides in domestic dwellings is undesirable, costly and often impractical. The impetus for managing cockroach populations in a more efficient and environmentally friendly manner has been created by two main factors. Firstly, the difficulties inherent in achieving really effective and lasting control of cockroaches in complex buildings, and secondly, the increasing scrutiny by regulatory bodies, environmental groups and the media of the problems caused by infestations of cockroaches, and of the techniques and materials used in their control (Owens, 1986).

During the past 20 years, considerable effort has gone into exploring the possibilities of controlling cockroaches and other insects with juvenile hormone analogues (JHAs). These compounds have extremely low toxicity to vertebrates. For example, the acute oral LD50 (rat) of hydroprene = >34,000 mg/kg. Moreover, their biological action (disruption of growth and reproduction) is highly specific and occurs only in insects and some related arthropods. These unique toxicological properties make JHAs especially suitable for use in the domestic environment and in food manufacturing or handling areas. The effects of JHAs on cockroaches and their potential as control agents were demonstrated several years ago (Das and Gupta, 1974; Edwards, 1975; Riddiford *et al.*, 1975; Masner *et al.*, 1978; Staal *et al.*, 1985). More recently, studies in the United States have demonstrated the practical efficacy of two JHAs (hydroprene and fenoxycarb) in control programmes against the German cockroach (Bennet *et al.*, 1986; Brenner *et al.*, 1988). In previous laboratory tests (Edwards and Short, 1988; Short and Edwards, 1992) we reported the effects of hydroprene on reproduction and development in *B.orientalis*, and demonstrated that surface deposits of hydroprene (ca 25mg/m^2) could eliminate small confined populations. Later in a large scale trial (Edwards and Short, 1993), a semi natural population of *B.orientalis* in a simulated domestic environment was completely eradicated by half yearly treatments with (S)-hydroprene delivered from a total release fogger at a rate calculated to give 25mg/m^2 (floor area).

In the present study we present the results from some preliminary laboratory tests, and from a further large scale test in a simulated domestic environment, in which we have applied (S)-hydroprene utilising an extremely simple and highly practical application technique involving suspended filter papers impregnated only with the active ingredient (hydroprene) and an anti-oxidant.

MATERIALS AND METHODS.

Insects

All cockroaches used in these trials were bred from a laboratory culture of *B.orientalis* that was derived from insects originally collected in 1986 from a London hospital. Due to the relatively short

Proceedings of the First International Conference on Urban Pests.
K.B. Wildey and Wm H.Robinson (editors). 1993

time that this strain has been in laboratory culture, we believe that it is representative of a field population. All insects were bred at 27°C and 45% r.h. prior to the tests, and were fed *ad libitum* on standard laboratory cockroach food (wheatfeed, rolled oats, yeast, fishmeal, dog chow and ground peanuts, 14:14:3:6:6:2; w/w) throughout the experiments.

Laboratory evaluation of hydroprene point sources:

These tests were conducted in glass tanks (30 x 20 x 20cm) each containing 50 nymphs estimated (by age after hatch) to be in the 5th or 6th instar (Short and Edwards, 1991). Food and water was provided *ad libitum*, and the tanks were kept at 25°C and 45% r.h. The floor of each tank was covered with a close-fitting vinyl tile (area 0.0486 m2) held in position with flexible caulking adhesive (Instant Polyfilla). The tops of the tanks were covered with wire gauze lids, which themselves were covered on the inside with a sheet of filter paper. The upper sides of the tanks were coated with "Fluon" to prevent cockroaches escaping. Each tank also contained identical folded cardboard harbourages. Nymphs in these tanks were exposed to (S)-hydroprene released from treated filter papers (Whatman No.542, 5.5cm dia.). Cockroaches were exposed from the 5th or 6th instar until the formation of the adult stage. The hydroprene treated filter papers (one per tank) were suspended by metal clips from the centre of the gauze lid of the tank, such that no direct physical contact by cockroaches was possible.

Hydroprene treatments

Technical grade (S)-Hydroprene (ethyl [S]-3,7,11-trimethyl-2[E],4[E]-dodecadienoate) was supplied by Zoecon Corporation, Dallas, Texas, U.S.A. In order to calculate the doses applied to the filter papers, it was (arbitrarily) assumed that 20%, 10% or 1% of the hydroprene applied to the filter paper might end up on the tile. These assumed release rates were necessary because precise information on release rates or on the mobility of hydroprene was unavailable. Short and Edwards (1992) have shown that direct treatment of the substrate at 25mg/m^2 S-hydroprene gave complete inhibition of reproduction, and was sufficient to eliminate small, confined populations of *B.orientalis*. Thus, in an attempt to get 25mg/m^2 onto the tile at the assumed mobility rates (1, 10 or 20%) the total quantities of (S)-hydroprene applied to the papers were 6.075 mg, 12.15 mg or 121.5 mg respectively. Each dose was replicated twice. Filter papers were treated with appropriate quantities of technical (98% pure) (S)-hydroprene disolved in acetone. These solutions were dispensed evenly over the filter paper surface with a glass pipette, and the acetone allowed to evaporate for 1hr before the papers were placed in the treatment tanks. Filter papers treated with acetone only were used as controls. In addition, a series of identical tests was conducted in which the hydroprene was mixed with 20% (w/w) of the anti-oxidant butylated hydroxy toluene (BHT) prior to dispersal on the filter papers. The incorporation of this material may, according to the manufacturers, stabilise hydroprene, and result in a more effective treatment.

Measurement of effectiveness

The effectiveness of treatments was measured by recording the number of adults produced from treated nymphs, the number of adults with deformed wings or terminalia, and the mortality of insects prior to and at metamorphosis. In addition, 10 newly-moulted adult females were selected randomly from each treatment dose/formulation, and their ability to produce viable oothecae after pairing with untreated males was recorded.

Artificial Domestic Environments

Two steel freight containers (6 m x 2.5 m x 2.5 m) hired from Boxrent Ltd, Gerrards Cross, Bucks. U.K., were converted into artificial domestic environments. Each container was internally insulated with 1" fire-resistant polystyrene and fitted with melamine wall and ceiling panels and an internal door. The internal door had a 30 cm2 gauze-covered vent cut in it to allow continuous air exchange with the external environment to take place. The floor of each container (area 11.6 m^2) was covered

with vinyl flooring glued to the floor surface. All panel and floor joins were sealed with "Unibond" waterproof silicone sealant to prevent escape of cockroaches. Each container was supplied with a humidifier and thermostatic fan heater, three cockroach food troughs and several water fountains. A melamine work bench was also placed in each container.

Cockroaches were provided with a mixture of cardboard harbourages : either tubes (2-5 cm diameter x 12 cm) or boxes (24x11x11 cm or 60x24x24 cm). The total surface area of the harbourages was approximately 12 m2. All harbourages were placed around the sides of the container so that the central area was left uncluttered and could be used for food and water supplies and for trapping. Temperature and humidity conditions were maintained (as far as possible) at 25°and 45% r.h. In an effort to prevent U.K. summer temperatures raising the internal temperature, each container was painted white externally to reflect sunlight. Although the temperature remained relatively constant throughout the trial, some variation was inevitable; the minimum and maximum temperatures recorded were 17°C and 34°C respectively. Although these artificial domestic environments were sealed to prevent the escape of cockroaches and the outer doors were generally kept closed, air exchange through the gauze door vent was continuous, and each container was opened and entered 2-3 times each week.

Insects:

Each container was infested with a mixed population of 3,300 insects comprising 1,000 small nymphs, 1,000 medium nymphs, 1,000 large nymphs (size categories arbitrary) and 300 adults. In addition, 100 randomly selected oothecae were introduced into each container at the start of the experiment. The sex of all adults was determined prior to introduction to ensure that the adult sex ratio was close to 1:1. The cockroaches were fed *ad libitum* on standard laboratory cockroach food (see above) for the duration of the trial, and water was continuously available. Both populations were allowed to stabilise for 10 weeks before treatment.

Hydroprene treatment:

After 10 weeks, each container was treated with two point sources. These consisted of treated filter papers (11 cm dia., Whatman No.1) suspended from the ceiling of the containers beneath a cockroach-proof guard. The point sources were suspended centrally towards the ends of each container. For the hydroprene treatment, two filter papers were treated with 750mg of technical grade (98% pure) (S)-hydroprene disolved in 2ml of acetone, incorporating 150 mg of the anti-oxidant butylated hydroxy toluene. Based on an assumed release rate of 20%, this treatment rate was expected to deliver hydroprene at approximately 25mg/m^2 floor area. After airing for 24 h. to remove solvent, the the treated papers were suspended in the manner described above. Two filter papers treated with anti-oxidant only were suspended in the control container. Treated and control filter papers were replaced at 6 month intervals until four treatments had been performed.

Monitoring cockroach populations:

The population of cockroaches in each container was monitored using live-catch "Roatel" traps so that the insects could be returned to the population after each monitoring. The traps were supplied by Killgerm Chemicals, Ossett, W.Yorkshire, and were baited with "Roatel" bait from the same supplier. Six traps were placed in marked positions on the floor of each container and left in position for 24 h. After this time, each trap was examined. Insects from each trap were counted,the sex of adults determuned, their deformities recorded, and the number of nymphs in each size catagory (small, medium and large) was recorded. Monitoring was performed each week for the 10 week acclimation period prior to treatment, and at intervals of 2 weeks thereafter.

The trap catches for the first 10 weeks before treatment were averaged to give a baseline initial population value. After the first treatment, the trap catches from each pair of 2 weekly monitorings were combined and divided to give an overall monthly (4 weekly) mean for each container. In addition, the numbers of deformed adults and the numbers of small, medium and large nymphs were expressed as a percentage of the total catch.

Proceedings of the First International Conference on Urban Pests.
K.B. Wildey and Wm H.Robinson (editors). 1993

TABLE I. EFFECT OF HYDROPRENE POINT SOURCE ON DEVELOPMENT IN *BLATTA ORIENTALIS*.

DOSE ON SUSPENDED FILTER PAPER	NUMBER OF NYMPHS IN TEST	NUMBER OF ADULTS PRODUCED	% ADULT DEFORMITY	% MORTALITY
		WITHOUT ANTIOXIDANT		
CONTROL	100	95	1.1	5.3
6.075mg/f.p.	100	99	80.8	2.0
12.15mg/f.p.	100	96	95.8	5.2
121.5mg/f.p.	100	99	100	10.2
		WITH ANTIOXIDANT		
CONTROL	100	98	1.0	2.0
6.075mg/f.p.	100	100	99	2.0
12.15mg/f.p.	100	99	93.9	6.1
121.5mg/f.p.	100	96	100	19.8

TABLE 2. EFFECT OF (S)-HYDROPRENE POINT SOURCE ON REPRODUCTION IN *BLATTA ORIENTALIS*.

DOSE ON SUSPENDED FILTER PAPER	% FEMALES PRODUCING OOTHECAE	MEAN INCUBATION TIME	MEAN NUMBER OF NYMPHS/OOTH	% HATCH (N=30)
		WITHOUT ANTIOXIDANT		
CONTROL	100	61.410.9	15.410.2	76.7
6.075mg/f.p.	0	0.0	0.0	0.0
12.15mg/f.p.	0	0.0	0.0	0.0
121.5mg/f.p.	0	0.0	0.0	0.0
		WITH ANTIOXIDANT		
CONTROL	100	62.710.8	14.010.8	79.3
6.075mg/f.p.	0	0.0	0.0	0.0
12.15mg/f.p.	0	0.0	0.0	0.0
121.5mg/f.p.	0	0.0	0.0	0.0

Monitoring reproduction.

Throughout the trial, at intervals of 4 weeks, 20 trapped adult females from each container were isolated in a small glass tank with several adult males (also from those trapped). These insects were held in these tanks inside each container until 10 oothecae had been produced. After this time the adults were released and the oothecae were placed individually in glass specimen tubes (3" x 1"). These tubes were then removed to the laboratory for incubation at 25°C and 70% r.h. When adult females were unable to produce oothecae (due to the effect of the treatment) they were held for 4 weeks and then released. Oothecae collected in the manner described were monitored for hatch (viability) and for the numbers of nymphs produced per ootheca. Oothecae that did not hatch within 4 months of production were discarded.

RESULTS

Laboratory evaluation of hydroprene point source treatment.

Exposure of nymphs to point sources of hydroprene gave results that closely resembled those reported by Short and Edwards (1992) after exposure of nymphal *B.orientalis* to surface treatments of hydroprene. The tests reported here have demonstrated that point sources of hydroprene are effective in the sterilisation of adults emerging after treatment (Tables 1 & 2). There was a high percentage of deformed adults both when hydroprene was applied alone and when the anti-oxidant BHT was incorporated into the source (Table 1). At the lowest dose tested, stabilisation of hydroprene with the anti-oxidant appeared to increase the percentage of adults with deformities. Nymphal mortality remained at about 5% for treated insects and controls in most treatments. However, mortality at metamorphosis at the highest exposure rate was substantially greater than was previously reported for hydroprene surface treatments (Short and Edwards, 1992). Moreover, in both tests at the highest exposure level, the developmental period required for nymphs to reach

FIGURE 1. CHANGES IN POPULATIONS OF B.ORIENTALIS IN CONTROL AND TREATED (HYDROPRENE POINT SOURCE) SIMULATED DOMESTIC ENVIRONMENTS

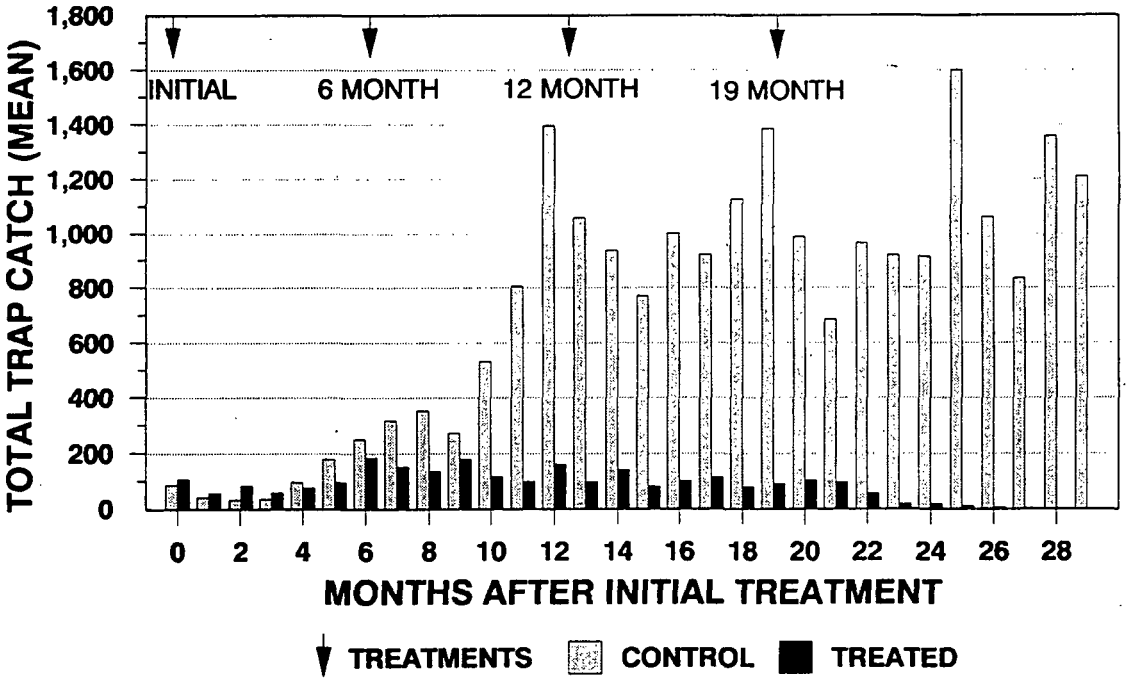
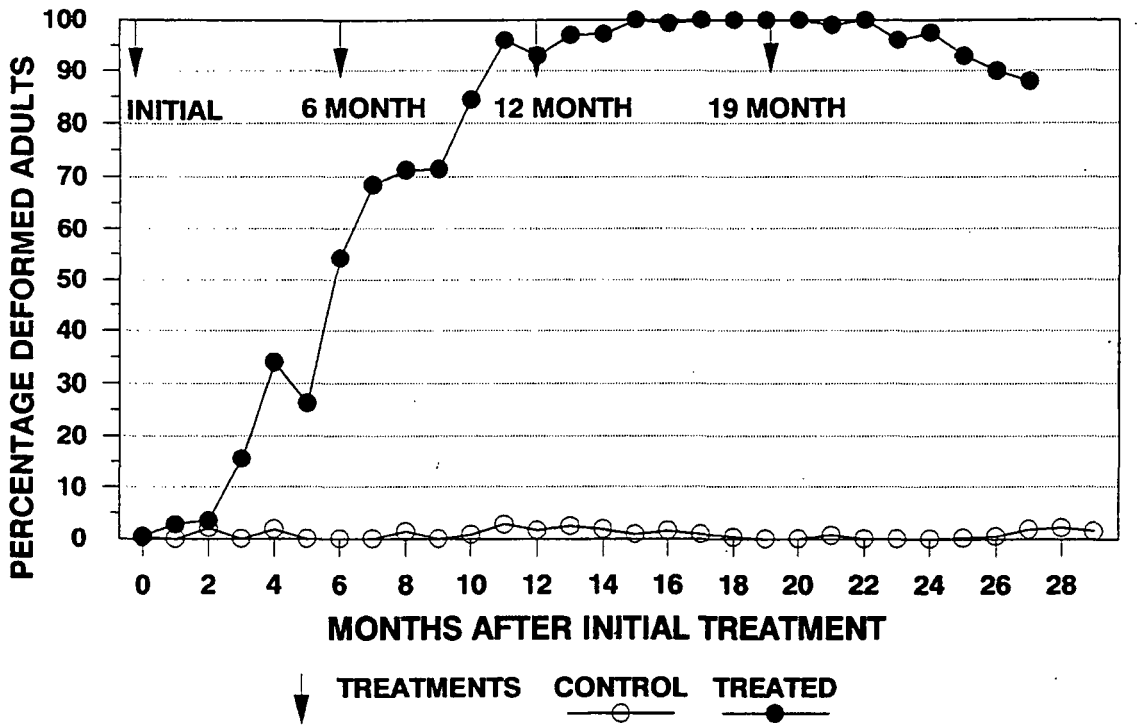


FIGURE 2. PERCENTAGE OF DEFORMED ADULTS IN TRAPS FROM CONTROL OR HYDROPRENE TREATED SIMULATED DOMESTIC ENVIRONMENTS



Proceedings of the First International Conference on Urban Pests.
K.B. Wildey and Wm H.Robinson (editors). 1993

adulthood (10 months) was substantially increased compared to the controls (6 months). More importantly, adults emerging from all hydroprene treatments were sterile. None of the selected females at any of the exposure rates were capable of producing viable oothecae (Table 2) whether the anti-oxidant was present or not.

Artificial domestic environments: Changes in cockroach populations.

The monthly means for total trap catch for each container are shown in Fig. 1. and Table 3. The overall mean trap catch for each container for the ten weeks prior to treatment were 88 and 106 insects for the control and treated containers respectively. These values represent only about 3% of the initial starting populations of 3,300 insects. For the first six months after treatment, both populations of cockroaches increased (6 month trap catches were 252 and 186 in the control and treated containers respectively). After this time, the population in the control container continued to rise and remained high for the duration of the trial. However, the population of *B.orientalis* in the container treated with hydroprene point sources gradually declined after 6 months, until no insects were trapped 28 months after the initial treatment.

The percentage of deformed adults recorded (Fig. 2, Table 3) in the treated container increased during the first 12 months, reaching 96% at 11 months after initial treatment. After this time, adult deformity remained above 90% until shortly before the end of the trial. The apparent fall in level of adult deformity during the last few months (Fig. 2) was due to the consistent recapture of two undeformed adult males. These two insects may have been introduced from the neighbouring control container from which a few escapes were occuring during the latter months of the experiment. In the control container the level of adult deformity in trapped insects remained below 5% throughout the trial.

Small nymphs (expressed as a percentage of total catch) remained present in the control container for the duration of the trial, although they rarely accounted for more than 33% of the total catch (Table 3). In the hydropene treated container, small nymphs were trapped regularly for the first 14 months, but accounted for less than 10% of the catch after 6 months. For five consecutive months (between 17-21 months after initial treatment) no small nymphs were trapped in the treated container. However at the 22 month monitoring, a single small nymph was trapped for two consecutive monitorings, and another small nymph was trapped at the 25 month monitoring. These insects were probably inadvertantly introduced from the control container.

Numbers of medium and large nymphs trapped were also expressed as percentages of total catch (Table 3). In the control container, medium nymphs accounted for the greatest proportion of insects trapped after about one year. In the treated container, medium nymphs remained present until 25 months after the initial treatment. However, the 24 and 25 month figures may reflect the introduction of insects from the control container, since prior to this time there was a gradual

TABLE 3. EFFECTS OF (S)-HYDROPRENE POINT SOURCE TREATMENT OF POPULATIONS OF *B.ORIENTALIS* IN SIMULATED DOMESTIC ENVIRONMENTS.

TIME AFTER TREATMENT (MONTHS)		0	1	2	3	4	5	6	7	8	9
TOTAL CATCH	control	87.8	42	31.5	34.5	98	179	251.5	317.5	353.5	273
	treated	106	56.5	84	59.5	76.5	97.5	186	153.6	136.5	180.5
% DEFORMED ADULTS	control	0.3	0	2.1	0	1.9	0	0	0	1.4	0
	treated	0.6	2.8	3.6	15.6	34.1	26.4	54.3	68.5	71.3	71.5
% SMALL NYMPHS	control	6	33	17.4	56.5	14.1	16.4	11.7	5.7	13.7	35.2
	treated	12	20.5	9.8	26.1	24.7	27	27.3	8.7	5	0.7
% MEDIUM NYMPHS	control	21.4	28.6	10	5.9	13	20	22.4	12.3	15.6	16.4
	treated	22.8	19.3	14.3	16.6	19.8	22.4	20.5	20.1	8.6	14
% LARGE NYMPHS	control	15.5	3.8	6.2	10.2	11	6.4	8.2	5.2	9.9	8.2
	treated	15.6	12.1	11.3	17.2	9.8	12.2	12.5	8.2	10.5	13.7

TABLE 3. Continued....

TIME AFTER TREATMENT (MONTHS)		10	11	12	13	14	15	16	17	18	19
TOTAL CATCH	control	531.5	805	1395	1060	939	769	1002	923	1126	1385
	treated	118	99	163	96.5	142	82.5	101	115	80	91.5
%DEFORMED ADULTS	control	0.8	2.8	1.7	2.5	1.9	0.9	1.6	0.9	0	0
	treated	84.5	96	93	97	97.2	100	99.3	100	100	100
% SMALL NYMPHS	control	31	32.9	33.3	38.5	26.2	13.4	21.4	14.3	2.6	8.5
	treated	0.3	3.5	2.5	7	0.3	0	0.4	0	0	0
% MEDIUM NYMPHS	control	18.5	31.8	49.2	42.5	55.4	48.2	48.6	45.8	39.7	34.5
	treated	11.4	4.7	6	10.4	30.7	8.3	15.4	11.1	4.7	5.8
% LARGE NYMPHS	control	9.8	9.9	6.5	9.6	6.6	17	7.2	3.8	1.3	1.3
	treated	18.3	18.3	19.1	13.5	12.6	23.6	21.6	18.9	11	1.3
TIME AFTER TREATMENT (MONTHS)		20	21	22	23	24	25	26	27	28	29
TOTAL CATCH	control	989	684.5	965	921.5	916	1600	1061	835	1358	1209
	treated	105.5	96	56	16.5	16	10	5	25	0	0
% DEFORMED ADULTS	control	0	0.7	0	0	0	0.2	0.5	1.9	2.2	1.5
	treated	100	99	100	96	97.5	93	90	88	-	-
% SMALL NYMPHS	control	10.4	5.2	7.6	11.5	9.7	20.9	11.9	5.7	5.0	1.8
	treated	0	0	2.1	0	0	3.9	0	0	0	0
% MEDIUM NYMPHS	control	31	34.5	38.4	37.2	46.8	56.3	63.9	54.1	58.7	41.4
	treated	1.4	0.6	2	0	11.1	3.9	0	0	0	0
% LARGE NYMPHS	control	1.5	2.1	4.1	7.3	6.1	5.7	7.1	13.2	10.8	27.6
	treated	0	0.5	0.7	2.5	11.9	0	10	0	0.2	0

reduction in numbers until 23 months when no medium nymphs were trapped in the treated container.

The percentage of large nymphs trapped in both containers remained a fairly small proportion of the total catch (Table 3). However, the percentage of large nymphs trapped in the treated container was gradually reduced to zero after about 24 months. The records of large nymphs trapped at 26 and 28 months refer to single insects, trapped once in both monthly monitorings, and may have been the same insects that we believe were inadverantly introduced as small nymphs at 22 and 25 months (Table 3).

After three consecutive monitorings had recorded zero catch in the treated container, all harbourages in that container were examined for the presence of live cockroaches. This examination produced 16 insects (14 deformed adults and 2 large nymphs) which were removed from the container, placed in a small glass tank (30 x 20 x 20cm) at 25°C, 45% r.h. and given food, water and harbourage *ad libitum*. These insects were monitored for mortality and reproduction weekly. Eight weeks after their removal from the treated container all insects were dead and no reproduction had taken place. Consequently, complete eradication of the population of *B.orientalis* treated with hydroprene point source occured 2 years and 3 months after initial treatment.

Reproduction in Treated and Untreated populations.

The number of oothecae collected each month and their subsequent hatch is shown in Table 4. In the control container ten oothecae were produced each month, within 3-4 days of holding the females, throughout the trial with the exception of the first month, when too few females were trapped. The hatch of these oothecae was variable over the duration of the trial but the overall mean viability (72%) was high. By contrast it was only possible to collect ootheca from females isolated in the treated container for the first 9 months. Despite being isolated for a full 4 week period, females were unable to produce oothecae after this time. However, during the early months of the trial when oothecae were being produced, they generally hatched (60%) to produce apparently normal nymphs.

TABLE 4. EFFECTS OF (S)-HYDROPRENE POINT SOURCE ON OOTHECA PRODUCTION AND VIABILITY IN *B.ORIENTALIS* IN SIMULATED DOMESTIC ENVIRONMENTS

TIME AFTER TREATMENT (MONTHS)	CONTROL NO. COLLECTED	CONTROL NO. HATCHED	*	TREATED NO. COLLECTED	TREATED NO. HATCHED
0	10	9	*	10	9
1	0	Too few trapped	*	0	Too few trapped
2	10	3	*	10	9
3	10	9	*	10	6
4	10	7	*	10	8
5	10	9	*	4	0
6	10	9	*	1	0
		RETREATMENT	*	6 MONTHS	
7	10	9	*	10	4
8	10	7	*	0	-
9	10	7	*	2	1
10	10	9	*	0	-
11	10	8	*	0	-
12	10	8	*	0	-
		RETREATMENT	*	12 MONTHS	
13	10	8	*	0	-
14	10	6	*	0	-
15	10	9	*	0	-
16	10	6	*	0	-
17	10	7	*	0	-
18	10	7	*	0	-
19	10	6	*	0	-
		RETREATMENT	*	19 MONTHS	
20	10	5	*	0	-
21	10	7	*	0	-
22	10	6	*	0	-
23	10	8	*	0	-
24	10	9	*	0	-
25	10	9	*	0	-
26	10	0	*	0	-
27	10	7	*	0	-
28	10	7	*	0	-
29	10		*	0	-

DISCUSSION

In previous studies with hydroprene, we have found that there is a very close correlation between the level of deformity in adult cockroaches exposed to hydroprene as nymphs, and the inhibition of reproduction (ootheca production) in females (Edwards and Short, 1988; Short and Edwards, 1991). We have also demonstrated that, using total release foggers, application rates of 25 mg/m2 floor area (nominal rates) are sufficient to induce greater that 95% adult deformity in treated populations, and to result in their eventual elimination (Edwards and Short, 1993). In the present exploratory laboratory tests with hydroprene point sources, all application rates of hydroprene prevented reproduction in the exposed insects that were monitored. However, at the lowest (6.075 mg) exposure rate when no anti-oxidant was present, the level of deformity recorded in adults was lower (80.8%) than for the other two exposure rates (where adult deformity was 96 and 100% respectively). At this lowest dose there may not have been enough hydroprene present to affect all exposed insects, and therefore to prevent reproduction in all of the population (although all ten females monitored were unable to produce oothecae). Previous container trials with hydroprene foggers (Edwards and Short, 1993) have indicated that approximately 95% sterilisation of adult females in a population would result in its eventual elimination. In the present exploratory laboratory experiments with hydroprene point sources combined with anti-oxidant, the lowest treatment rate produced 99% deformity (and hence inhibition of reproduction) in exposed insects. Consequently, this rate (scaled-up) was the treatment rate chosen for the experiment with hydroprene point sources in the artificial domestic environment. It is important to remember that this treatment rate was based on an assumed release rate of hydroprene from the filter papers of at

least 20% of the applied dose. Moreover, the preliminary laboratory tests had shown that this treatment rate could maintain >95% deformity (and hence sterilisation) of exposed insects. We do not, as yet, have accurate information on the amount of hydroprene applied to the filter papers that is released to the surrounding environment. However, we do know from previous experiments (Edwards and Short, 1993) that surface deposits of hydroprene ranging from 5 to 11 mg/m2 are sufficient to eliminate populations of *B. orientalis* in similar artificial domestic environments. We can, therefore, only suggest that the treatment rate used in the present study produced floor deposit rates of at least comparable levels. In making this suggestion, we are aware that not all of the hydroprene released from the filter papers would have ended up on the floor. This method of treatment would have undoubtedly resulted in a general dispersal of hydroprene over all surfaces including floor, walls and harbourages. In addition, some hydroprene may have accumulated in insect debris and on live insects themselves, since hydroprene has an apparent affinity for organic substrates (Staal *et al.*, 1985).

The 6 month treatment regime utilised in these container trials was sufficient to eventually eradicate a population of *B.orientalis* over a period of 2 years and 3 months. Although a relatively simple population assessment, the trap catches were reasonably consistent from month to month and, we believe, accurately reflect overall changes in the control and treated populations. Moreover, although these results are based on only one treated and one control population, they are entirely consistent with previous results obtained with (S)-hydroprene against *B.orientalis* (Edwards and Short, 1988 and 1993; Short and Edwards, 1992) and with the results obtained in the present laboratory tests.

Hydroprene is a juvenile hormone analogue, and therefore has no significant direct toxic activity in insects including *B.orientalis* (Short and Edwards 1992). In addition, it has little (if any) effect on reproduction when insects are exposed after they have reached the adult stage. Thus, any population treated with such a compound is likely to show an initial increase in size until existing adults, capable of normal reproduction, have died of old age. Eventually however, these individuals will be replaced by sterile adults that have been exposed to the hormone analogue during the latter nymphal stages. In the artificial domestic environments this point was reached at about 6 months (Fig. 1) and thereafter the population slowly declined due to the inhibition of reproduction. The decline in population was not as rapid as that reported by Edwards and Short (1993) for a hydroprene fogger treatment in a similar environment. This is probably because the point source treatment reported here took longer to evenly disperse throughout the container environment and into the infestation. Some evidence that this was the case is derived from the fact that the point source treatment did not achieve >95% deformity in trapped adults until 11 months after treatment, whereas the same degree of adult deformity was achieved after 6 months when hydroprene was applied as a fog. The present laboratory tank tests showed that point sources of hydroprene were able to achieve 100% inhibition of ootheca production in the insects tested. In the artificial domestic environment treated with hydroprene point sources, oothecae production was completely stopped when the level of deformity in trapped adults measured 85% (ten months after the first treatment). In a previous study utilising hydroprene foggers (Edwards and Short, 1993), this level of reproductive inhibition was achieved more quickly (8 months after the first treatment). However, in a field situation it is likely that the disadvantage of this slight delay in achieving total reproductive inhibition would be far outweighed by the ease of application of the treatment. In addition, the final time taken to eradicate the treated population in the present study was not substantially different from the study utilising hydroprene foggers.

The fact that hydroprene point sources can eradicate a population of *B.orientalis* in an artificial domestic environment has been clearly demonstrated. In a field situation however, the time taken for eradication would probably be unacceptable in most situations. Consequently, it is more likely that hydroprene would be used in conjunction with a conventional insecticide treatment. This is not an entirely new approach, combination treatments of conventional insecticides with hydroprene were suggested by Edwards (1986); Edwards and Short (1988 and 1993); Short and Edwards (1992); and have been investigated against *B.germanica* (Bennett *et al.*, 1986; Brenner *et al.*, 1988). In a combination treatment, the simple application of hydroprene point sources could take place with minimal disturbance at the same time as the conventional treatment, or at a later monitoring exercise, with very little extra time expended. One or two point sources would need to be attached

Proceedings of the First International Conference on Urban Pests.
K.B. Wildey and Wm H.Robinson (editors). 1993

to the ceiling/wall of each room depending on room size. The activity of the conventional insecticide (spray, bait, dust etc.) would give a rapid reduction in extant cockroach population. The use of hydroprene would ensure subsequent, long term, protection against any significant increase in population, and would eventually result in the eradication of the infestation. Clearly, an integrated approach such as that mentioned above would have many advantages over existing conventional treatments. The toxicological properties of hydroprene also make its practical use extremely safe, especially in point source formulation and in situations where normal pesticide use is restricted. Despite the fact that little is understood about the nature of the motility of hydroprene, we believe that these experiments have demonstrated a number of very important properties of this molecule that could have great significance for the future of cockroach control techniques. Firstly, however, we wish to discuss the possible ways in which hydroprene could disperse from a point source and remain in sufficient quantity in the environment to affect a population of cockroaches.

It is clear from these experiments, that the main mode of dispersal of hydroprene from the point sources is by diffusion of hydroprene molecules through the air to the target insect population. However, we know from this and from previous experiments, that this diffusion is not simply a result of rapid and sustained evaporation of hydroprene into the atmosphere - if it were, then the continuous exchange of air between the air inside the container and the external atmosphere would continuously dilute the hydroprene concentration in the container until insufficient hydroprene was present to eradicate the cockroach population. Therefore, we believe that hydroprene molecules evaporate relatively slowly from the point source, and that air concentrations at any given time are relatively low. In addition, we suggest that hydroprene present in the atmosphere will preferentially accumulate on or in organic substaces (including cockroaches) over a period of time, and be less able to return to the atmosphere. In this way, organic substances would act as a partially irreversible "sink" or "trap" for hydroprene, largely witholding it from the circulating air, but maintaining it in sufficient concentration to affect cockroach populations. We are currently conducting further experiments to investigate these hypotheses.

There are two important implications of the ability of hydroprene to disperse from a point source. Firstly, this phenomenon would ensure that even normally inaccessible areas in an infested premise would eventually be treated without the need to dismantle equipment or to drill holes in void covers or cavity walls and floors. This would represent a major saving in the time taken to achieve a really thorough treatment and, greatly reduce the disruption of normal life of residents or employees in the infested premise. Secondly, the fact that hydroprene can be applied in an infested premise without the need for complex formulations containing solvents and emulsifiers, should improve the (already impressive) toxicological acceptability of such treatments. In conclusion, hydroprene point sources offer a unique oportunity to achieve effective control of cockroach infestations, with maximum ease of application and minimal toxicological hazard.

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K.B. Wildey and Wm H.Robinson (editors). 1993