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Mosquito control in Dar es Salaam. II. Impact of expanded polystyrene beads and pyriproxyfen treatment of breeding sites on *Culex quinquefasciatus* densities

D. C. CHAVASSE, J. D. LINES, K. ICHIMORI,* A. R. MAJALA,† J. N. MINJAS† and J. MARIJANI London School of Hygiene and Tropical Medicine, U.K., and *Urban Malaria Control Project, Ocean Road Hospital, and †Faculty of Medicine, Muhimbili Medical Centre, Dar es Salaam, Tanzania

Abstract. In two contrasting areas of Dar es Salaam (Ilala and Mikocheni) all enclosed breeding sites of *Culex quinquefasciatus*, such as latrines and septic tanks, were treated with a floating layer of expanded polystyrene beads. 7 months later checks in both study areas revealed only one site (from which the polystyrene had been removed during emptying) containing immature stages of *Cx quinquefasciatus*.

Open breeding sites such as areas of flooded land and blocked drains were treated with pyriproxyfen (an insect growth regulator) at a concentration of 0.1 ppm. Emergence of *Cx quinquefasciatus* adults from these sites was inhibited for 4 weeks during the rainy season and for up to 11 weeks during the dry season.

The problem of mosquito breeding sites caused by bathroom sullage water was addressed through a combination of health education and indirect pressure from the Urban Malaria Control Project (UMCP) via local community leaders. Households responsible for these sites were encouraged to eliminate them by diverting the water into an enclosed drainage structure, usually a pit latrine. After two weekly visits 64.7% of households had complied and 93.4% had complied after five visits. 5 months later, only 15.7% had reverted to allowing sullage water to collect into puddles.

Densities of *Cx quinquefasciatus* adults dropped by 76.7% in Mikocheni and by 46.2% in Ilala following intervention, but increased by 84.9% and 25.6% in two untreated comparison areas. The reasons for differential success of the combined interventions in the two treated areas are discussed.

Key words. Polystyrene beads, pyriproxyfen, *Culex quinquefasciatus*, vector control, Tanzania.

Introduction

In Dar es Salaam and Tanga, the two main coastal cities of Tanzania, East Africa, the Urban Malaria Control Project (UMCP) has implemented malaria vector control activities since 1988. It was soon realized that, because the great majority of mosquitoes biting people in these urban areas are not malaria vector *Anopheles* spp., control of the pest species *Culex quinquefasciatus* Say was necessary to ensure public support for the project (UMCP, 1988).

Prior to the testing of intervention measures, a survey of *Cx quinquefasciatus* breeding sites was carried out in the Ilala and Mikocheni areas of the city (Chavasse *et al.*, 1995). It was found that the main types of enclosed breeding sites comprised pit latrines, soakage pits, septic tanks and cess pits. Pit latrines were the most numerous but the least likely to contain visible water suitable for mosquito

Correspondence: Dr D. C. Chavasse, Vector Biology and Epidemiology Unit, London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London WCIE 7HT, U.K.

oviposition, whereas septic tanks and cess pits were fewer but produced more mosquito pupae per site. All four types of site were more or less equally important in Ilala, whereas in Mikocheni latrines harboured about 60% of the pupae and most of the rest came from septic tanks and cess pits. In both areas ditches, storm drains and collections of bathroom sullage water were important open breeding sites of *Cx quinquefasciatus*. Mikocheni also had large areas of grassland, seasonally flooded with polluted water where *Cx quinquefasciatus* and other mosquitoes, including anophelines, bred abundantly.

The treatment of enclosed bodies of water with a floating layer of expanded polystyrene beads (EPB) has been shown to prevent mosquito breeding (Reiter, 1978; Sharma *et al.*, 1985; Curtis *et al.*, 1989; Maxwell *et al.*, 1990). EPB treatment has a number of advantages over application of insecticides. Resistance is not a problem since the beads suffocate the aquatic stages. The beads do not rot, therefore, for as long as they remain in place, they continue to prevent breeding, making them highly cost effective (Curtis *et al.*, 1989). In the town of Makunduchi, Zanzibar, Maxwell *et al.* (1990) treated all wet pit latrines with EPB and recorded a 98.2% decrease in biting by *Cx quinquefasciatus*. That high degree of control was achieved in isolation, since Makunduchi is far from other conurbations and, apart from pit latrines, there were few other breeding sites. In Dar es Sallam, treatment by Curtis *et al.* (1989) of 120 wet pits in an inner city area was apparently followed by an 80% reduction in mosquito numbers, relative to the untreated area, although it took 4 months for this decrease to be achieved.

It has long been known that, in Dar es Sallam, *Cx quinquefasciatus* is resistant to organophosphate insecticides (Curtis & Pasteur, 1981; Curtis *et al.*, 1984; Amin & White, 1985), so an insect growth regulator, pyriproxyfen (S-31183), was chosen for the treatment of open breeding sites where neither EPB treatment nor destruction of the site were feasible. Pyriproxyfen is a juvenile hormone mimic, affecting aquatic stages of mosquitoes while remaining safe to non-target organisms (Mulla *et al.*, 1986). Small-scale field trials have revealed that a dose of 0.1 ppm is effective in inhibiting emergence of adult *Anopheles punctulatus* in the Solomon islands for 2 months (Okazawa *et al.*, 1991), of *An.stephensi* in India for 3 months, but of *Cx quinquefasciatus* for only 2 weeks (Ansari *et al.*, 1991). The effect of concerted use of pyriproxyfen on adult mosquito densities has not been evaluated previously.

In this study we attempted to control *Cx quinquefasciatus* in the two study areas by integrating the methods discussed above in an appropriate manner. Factors which affected the success of the initiatives and the entomological results are reported.

Materials and Methods

Study areas and schedule of activities. Ilala and Mikocheni areas for intervention in Dar es Salaam were surveyed by Chavasse *et al.* (1995) who reported the numbers of actual and potential breeding sites of *Culex quinquefasciatus*. Expanded polystyrene beads were applied to the enclosed sites, first in Ilala during November and December 1991, and then in Mikocheni in February and March before the rainy season began in April 1992. Pyriproxyfen was applied to the open sites in Mikocheni in early May; when monitoring showed that efficacy had expired, the second application then followed in June 1992. The only application of pyriproxyfen to open sites in Ilala was carried out at the beginning of July 1992, at the same time that the health education campaign for destruction of sullage water sites was underway.

Polystyrene bead application. Expanded polystyrene beads (EPB) (Shell, styrocell grade R543 FE) were packed into polypropylene sacks (30 litres) after steam expansion in a local factory normally engaged in production of polystyrene storage boxes. EPB were applied to all enclosed potential breeding sites (i.e. on-site sanitation structures), unless there was no space for the beads or it was felt that the beads would be lost through flooding in the rainy season. One sack of beads was sufficient to treat a pit or tank with water surface area of up to 5 m^2, forming a layer of 0.5–1 cm on the water surface.

Pyriproxyfen application. A target concentration of 0.1 ppm pyriproxyfen was applied to the water of all open breeding sites. The pyriproxyfen formulation used depended on the type of site to be treated and the prevailing weather conditions. For breeding sites up to a few square metres in area (e.g. shallow flooded rubbish pits), a 10% EC formulation diluted to 1% was applied with a graduated pipette. The same formulation was applied, using a compression sprayer (Hudson X-pert), to large areas such as flooded fields. The spray concentration of pyriproxyfen varied from 0.01% to 0.05%, calculated from the measured output of the sprayer at average walking speed and the estimated depth of water. Because most of the larvicide remained on the grass leaves above the water level, this method was used only when rain was expected within a day or two and would wash the pyriproxyfen into the water. By the time of the second application in Mikocheni, rainy days were infrequent, so 0.5% granule formulation was applied to grass covered sites, the granules being able to penetrate through to the water. Application was achieved by shaking the granules out of plastic detergent bottles with holes in one end. Due to the difficulty of applying the granules evenly, the EC formulation was sprayed wherever possible. Shallow sullage water sites in Ilala, 46% of which contained mosquito aquatic stages, were treated with pyriproxyfen EC during the first visit made by the health education team concerned with source reduction of these sites, because it was not known how quickly the households would respond and a rapid impact was desired.

Source reduction of sullage water breeding sites. In Ilala, the 136 houses which had no enclosed drainage for bathroom sullage water (Chavasse *et al.*, 1995) were visited by a two-person team which decided on the best method of eliminating the potential breeding site caused by water being discharged to an open pool outdoors. In the majority of houses the bathroom is next to the latrine; therefore a hole made in the edge of the floor adjacent to the latrine

allowed the water to pass into the latrine pit. At the same time the hole through which water was discharged outdoors was blocked with a piece of wood. In some instances it was easier for the water to be directed into a nearby soakage pit. Whenever possible, actions were recommended which required no expenditure by the household but, in a few cases, there was no alternative to building a new soakage pit specifically to receive the bathroom sullage water.

The households were informed that a further visit would be made after 1 week. These weekly visits continued until the breeding site had been destroyed, or up to a maximum of five visits. If the site persisted after three visits, an official letter demanding action, signed by the local political party chairman, was delivered. 4 or 5 months after the initial visit, a follow-up check was made to see how many households had reverted to allowing water to collect outside the bathroom. At this time, households were also asked if they were experiencing any problems with the new system for collecting the sullage water.

Barrier zone. After completing the primary applications of EPB, all open and enclosed breeding sites of *Cx quinquefasciatus* 300 m from the perimeter of both study areas, Ilala and Mikocheni, were treated with either EPB or pyriproxyfen. These barrier zones were created in an attempt to prevent the immigration of mosquitoes from outside the treated sites.

Entomological evaluation. Numbers of adult mosquitoes were monitored using two systems of sampling. (1) Long-term low-intensity sampling was carried out in both intervention areas (Ilala, Mikocheni) and in two untreated comparison areas (Magomeni, Temeke). In each of the four areas, two rooms were monitored every fortnight using CDC light traps set beside beds equipped with untreated bednets (Lines *et al.*, 1991). This system was introduced in March 1991, 7 months prior to the start of EPB application in the first study area (Ilala) and continued until October 1992. (2) Short-term intensive sampling was undertaken in Ilala and Mikocheni before and after intervention. Seven rooms were monitored using CDC light traps for ten nights prior to EPB application and thereafter for three nights per week until the end of September 1992.

To assess the efficacy of EPB in preventing breeding in individual sites, mosquito exit traps (Curtis & Hawkins, 1982) were placed over on-site sanitation structures to catch emerging mosquitoes. To assess the impact of pyriproxyfen, mosquito emergence was monitored in three treated open sites. Pupae were collected from each treated site and one untreated comparison site, once per week, and taken alive to the laboratory. The proportion of pupae from which adult mosquitoes emerged successfully within 24 h was recorded for each site sampled.

Results

Management of on-site sanitation systems

A pre-intervention survey revealed that the majority of sites were emptied every 1–3 years. Septic tanks and cess pits were emptied by suction into slurry tankers, whereas latrines and soakage pits were usually emplied by bucket. Septic tanks and cess pits were emptied more frequently than latrines, presumably because they received greater volumes of water. The average reported emptying interval for latrines was 40 months. This was corroborated during the 11-month follow-up survey of treated pits, when it was found that 28% had been emptied. In Mikocheni 87% of households reported that their pits had never been emptied, compared to only 18% in Ilala. Mikocheni sites were emptied more frequently than those in Ilala, probably because of the high water table and shallower pits in Mikocheni.

Efficacy of expanded polystyrene bead (EPB) treatments in enclosed sites

EPB treatments were applied to 1188/1544 = 77% of on-site sanitation structures in Ilala and 613/755 = 81% of those in Mikocheni (Table 1); the remainder of sites were too full to accommodate an EPB layer. Only 4.8% and 3.5% of the full pits contained visible water, the remainder being covered in scum that prevented mosquitoes breeding. Exit traps placed over full pits caught no newly emerged mosquitoes.

The possibility of sites that had been full at the time of treatment becoming productive later, after emptying, was investigated by serial surveys of 152 full on-site sanitation structures at Ilala. One month after the original survey twenty-six (17%) had been emptied; 7 months later a total sixty-five (43%) had been emptied. None of these sixty-five emptied sites contained *Cx quinquefasciatus* aquatic stages when they were inspected. All were then treated with EPB.

In Ilala, 122 representative enclosed sites were checked during a follow-up survey and all of them were found to have been treated with EPB. In Mikocheni, not all enclosed sites were treated because the layout of the area made systematic coverage impossible. During follow-up, 6/94 = 6.4% of sites surveyed were found to have been left untreated (see below), indicating that about 46 (i.e. 6.4% of 720) enclosed sites were not treated in the whole area and, as only 24% of sites contained larvae and/or pupae, no more than about 11 (i.e. 24% of 46) of these untreated sites were likely to have been positive.

The impact of EPB treatment on mosquito productivity in enclosed sites at Ilala was tested by two methods. One month after EPB application, thirty-eight of the sixty-eight sites that had contained mosquito aquatic stages before treatment were reassessed using exit traps. Only 34 mosquitoes were caught from 37% of these sites (Table 2); 76% of the females were gravid and therefore not newly emerged. 7 months later, all sixty-eight sites were assessed by dipping. Aquatic stages were found in only a single site, from which EPB had been removed during emptying. In Mikocheni, where pre-intervention surveys showed 24% positive breeding sites, a representative sample of ninety-one treated sites were checked after 7 months using exit traps. Mosquitoes were caught in thirteen (14%) of these sites, but again numbers were small and 79% of the females were gravid (Table 2).

Table 1. Numbers of enclosed sites treated with expanded polystyrene beads, and the numbers untreated which were dry or which contained visible water.

	Ilala				Mikocheni			
	Treated		Not treated		Treated		Not treated	
Site type	No.	%	No. dry	No. wet	No.	%	No. dry	No. wet
Latrine	744	80	182	5	478	78	134	3
Soakage pit	302	67	140	9	27	100	–	–
Septic tank	83	90	8	1	40	95	1	1
Cess pit	59	84	9	2	33	92	2	1
Open pit*	0	–	0	0	35	100	0	0
Total	1188	77%	339	17	613	81%	137	5
			1544				755	

* Latrines under construction.

Table 2. *Culex quinquefasciatus* breeding in enclosed sites after treatment with polystyrene beads, measured by dipping or by exit traps. In Ilala, only sites known to contain larvae before treatment were sampled. In Mikocheni, trapping was carried out in a representative sample of all sites.

Study area	Months post treatment	Sampling Method	No. of sites checked	No. of sites +ve	No. of mosquitoes emerged	
					Males	Females (gravid)
Ilala	1	Exit trap	38*	14 (37%)	5	29 (22)
	7	Dipping	68*	1† (1.5%)	–	–
Mikocheni	7	Exit trap	91‡	13 (14%)	8	66 (52)

* Sites containing aquatic stages prior to bead application.
† The beads from this site were removed during emptying.
‡ Representative sample.

The effect of pit emptying on persistence of the EPB layer was assesed in representative samples of treated enclosed sites 11 months post-treatment at Ilala, and 7 months post-treatment at Mikocheni. Of the sites that had been emptied in Ilala, 34/122 (28%), only four still had an effective covering of EPB, sixteen were covered in scum, eight were dry and six were risk sites, because they contained visible water and were not effectively covered by EPB or scum; presence or absence of mosquito larvae was not recorded. In Mikocheni, out of ninety-four sites surveyed, only one had been emptied since application. Six wet sites were found to have no EPB and no scum, so presumably had never been treated, and a further ten had an ineffective EPB layer, probably due to under-treatment. Mikocheni therefore had sixteen risk sites, although adult mosquitoes were caught emerging from only two of them.

Pyriproxyfen efficacy in open sites

Table 3 shows the impact and persistence of pyriproxyfen in the three monitoring sites. For 4 weeks following the first treatment, emergence of *Cx quinquefasciatus* adults was completely inhibited. By the fifth week, a proportion of pupae hatched from all three sites, indicating the need for retreatment. Following the second treatment, by which time rainy days were infrequent, mosquito breeding was completely prevented for up to 11 weeks. Effects on non-target organisms were not recorded.

Source reduction of bathroom sullage water sites

Table 4 shows that 93.4% of households had eliminated their puddles of bathroom sullage water, following up to five visits by the health education team. The majority (64%) complied after just two visits. Of those that complied, 93% simply had to divert their sullage water into an existing on-site sanitation structure, usually a pit latrine. Nine households built a new soakage pit to receive the sullage water. After 4–5 months, only 15.7% of households had re-opened the blocked exit in the bathroom, allowing sullage water to collect outside again. When asked whether there were any problems with the altered system, 34.4% of those who originally complied said that the structure receiving the water became full quicker since sullage water had been passing into it. However, this was not supported by comparative data on the emptying frequency. The

Table 3. Weekly emergence rates of *Cx quinquefasciatus* adults (within 24 h) from pupae collected from three breeding sites in Mikocheni after treatment with pyriproxyfen during different seasons.

	Percentage of pupae hatching successfully			
	Rainy season		Dry season	
Week post-treatment	Treated	Control	Treated	Control
	% (*n*)	% (*n*)	% (*n*)	% (*n*)
0	0 (147)	56 (16)	0 (125)	87.5 (40)
1	0 (90)		0 (180)	66.0 (50)
2	0 (73)	66 (29)	0 (160	43.3 (60)
3	0 (242)	60 (15)	0 (118)	28.0 (25)
4	0 (20)		0 (50)†	56.0 (25)
5	38.5 (13)		0 (85)	60.0 (25)
6			0 (25)	40.0 (25)
7			0 (25)‡	28.0 (25)
8			0 (22)	56.0 (25)
9				
10			0 (25)	56.0 (25)
11			0 (40)	52.0 (25)
12			50.5 (85)	60.0 (30)

† Site 1 dried out.
‡ Site 2 dried out.

Table 4. Proportions of bathroom sullage water breeding sites eliminated by households in Ilala following appropriate adivce given by the health education team.

No. of sites	No. with pupae	Total no. eliminated	No. destroyed after two visits	No. reverted 5 months after elimination
136	62 (45.6%)	127 (93.4%)	88 (64.7%)	20 (15.7%)

Table 5. Geometric mean numbers of female *Cx quinquefasciatus* per light trap in the treated and untreated comparison areas: March–October 1991 (before treatment) and March–October 1992 (after treatment).

Study site	Before treatment	After treatment	Change (%)
Intervention treated			
Mikocheni	245.1	57.0	76.7** (reduction)
Ilala	67.7	34.8	46.2* (reduction)
Untreated comparison			
Temeke	19.1	35.5	84.9 (increase)
Magomeni	39.9	50.1	26.5 (increase)

Wilcoxon signed-rank test on paired months: * $P < 0.05$, ** $P < 0.01$.

average time since the last emptying for 357 latrine pits which received sullage water was 22 months. For 239 latrine pits which did not receive sullage water, the mean time since they were last emptied was only 18 months.

Entomological evaluation

Table 5 shows that, in both treated areas, Ilala and Mikocheni, there was a significant decrease in the geometric mean numbers of mosquitoes/light trap/night from March to October 1992, after intervention, compared with the same months in 1991, before treatment. In both untreated comparison areas, Temeke and Magomeni, there was a substantial increase in the number of mosquitoes in the year post-treatment. This increase reaches statistical significance if the results of the two control sites are grouped. The means for both control areas were used to correct the results for each treated area. The corrected reduction in mosquito numbers was 81.8% in Mikocheni and 58.0% in Ilala.

Fig. 1 shows the differential impact of EPB and pyriproxyfen on mosquito densities in the two treated areas. Pre-treatment densities were about 4 times higher in Mikocheni than in Ilala. Following application, the initial drop was similar in both areas: 72.3% and 73.4% respectively. At the onset of the rainy season, densities increased in both areas but subsequent pyriproxyfen treatment in Mikocheni brought about a further decline in densities. No such effect of pyriproxyfen treatment was seen in Ilala where mosquito numbers had returned to pre-treatment (dry season) levels.

Discussion

In this study of urban control of *Cx quinquefasciatus* by new methods, all enclosed potential breeding sites were EPB treated in anticipation of the rainy season, but this seems to have been unnecessary. We observed (Chavasse *et al.*, 1995) that the proportion of enclosed sites containing visible water did not increase during the rains, probably because the layer of scum on most pits simply rose with the water table. Therefore treatment of only those sites with visible water is sufficient to prevent mosquito productivity.

Restricting EPB application to sites with visible water would have markedly reduced the cost of treatment. In the two intervention areas, a total of 1901 sites were treated with sixteen drums (2 tonnes) of polystyrene beads costing $4368 ($2.3 per site). If sites with visible water only had been treated, 431 sites would have qualified, costing $991.3 and resulting in a saving of 77.3% of the expense.

Following EPB application in Ilala, mosquito breeding effectively ceased in treated sites: only negligible numbers of newly emerged *Cx quinquefasciatus* females were trapped in the surveyed sites in both Ilala and Mikocheni. Even 7 months post-treatment, breeding was found in only one of the original breeding sites in Ilala. EPB are capable of preventing breeding in on-site sanitation structures for at least 5 years (Curtis *et al.*, 1989), although the periodic emptying of these structures is likely to reduce the effective life of a single treatment. The reason why few pits were emptied in Mikocheni was apparently that, once they became full, a new one was dug and often the superstructure was moved over the new pit. In Ilala, the latrine

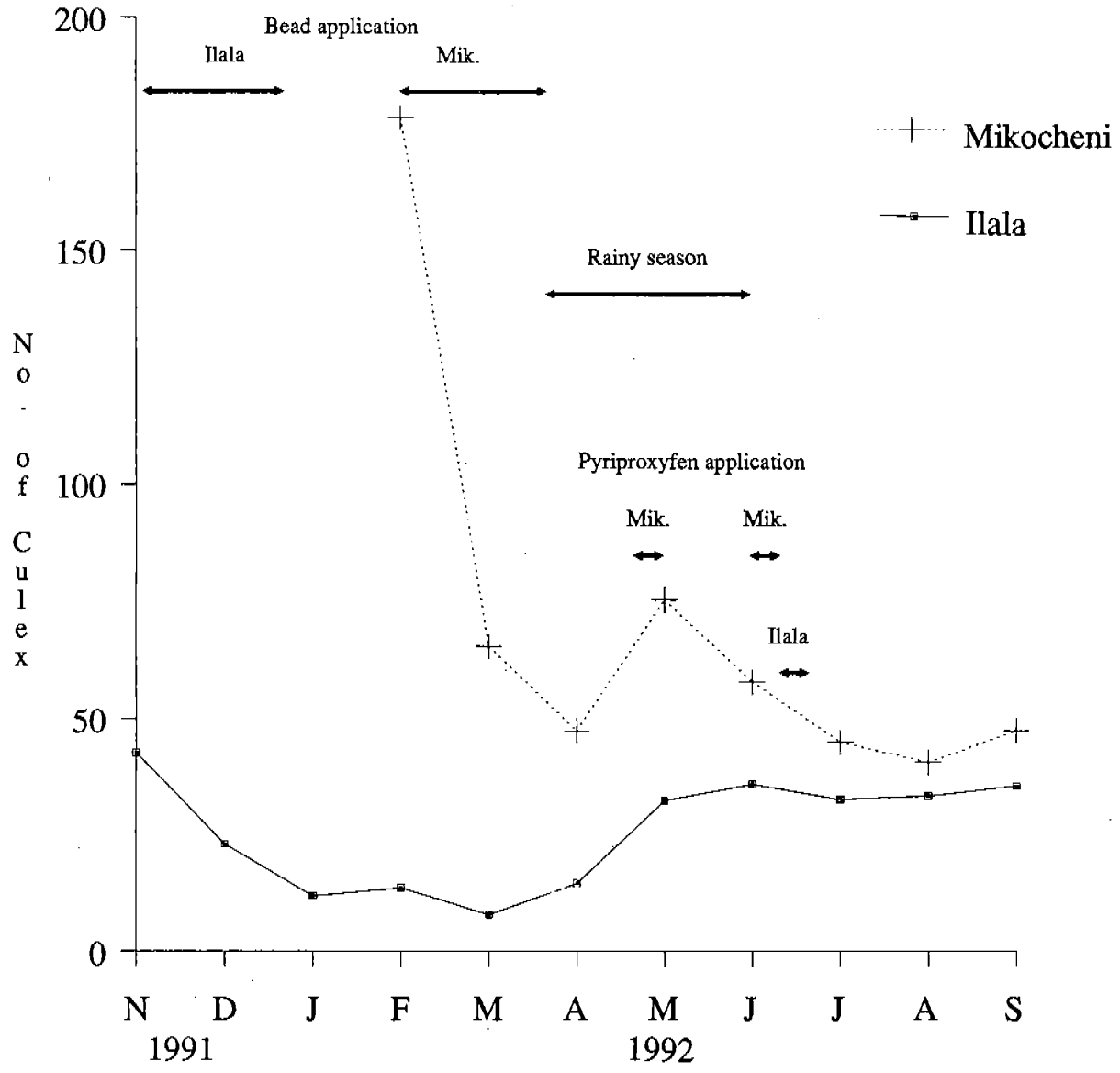

Fig. 1. Mean number of female *Culex quinquefasciatus* per light trap/night, before and after application of polystyrene beads and pyriproxyfen in Ilala and Mikocheni (Mik).

houses were permanent and space was limited, so that full pits had to be emptied.

These differences in emptying methods may have important implications for EPB persistence within a structure and the possibility of environmental pollution. One would expect EPB to be more likely to remain in a structure emptied by lorry, because the suction pipe could be placed below the floating layer. However, the vehicle operators avoid procedures which prolong the emptying time and therefore reduce their revenue.

Householders could insist that the correct procedure is followed by pit emptiers, before they are paid, in the interests of keeping the EPB layer in place. Where full pits are abandoned and new ones dug, as in Mikocheni, a new treatment of EPB is required every time. Although EPB were seldom encountered dispersed in the general environment during this study, part of the main stabilization ponds into which slurry lorries discharged from Mikocheni and Ilala was found to be covered with EPB of about 0.5 cm depth over 260 m^2 area, amounting to 1.3 m^3 of EPB removed from about forty enclosed sites. We estimated that about 520 of the treated enclosed sites would have been emptied. Reasons for the discrepancy in the amount of floating EPB and the number of emptied pits include (1) not all of the EPB are usually removed during emptying, and (2) presence of EPB in the surrouding soil indicated that past layers had been removed from the surface of the stabilization pond. In small quantities it is

unlikely that EPB cause any environmental problems, although they could reduce oxidation of the slurry if the layer extended over a large area.

Persistence of pyriproxyfen in open breeding sites is encouraging. Inhibition of adult *Cx quinquefasciatus* emergence for 11 consecutive weeks is the longest reported for this species. Ansari *et al.* (1991) found that 100% inhibition of *Cx quinquefasciatus* emergence was maintained for only 2 weeks (although 60–70% inhibition of emergence was maintained for 3 months). This relatively short-term effect may be due to the nature of the breeding site they treated (disused wells), where the lack of pyriproxyfen binding organic matter makes dilution more rapid (Mulligan & Schaefer, 1990). We agree with the conclusion of Ansari *et al.* (1991) that pyriproxyfen is likely to become the larvicide of choice in many mosquito control projects because of its efficacy against both *Culex* spp. and *Anopheles* spp., and because of the low toxicity in mammals and safety in the environment associated with insect growth regulators (Miura & Takahashi, 1974; Mulla *et al.*, 1986).

The response of the community to the idea of eliminating bathroom sullage water sites was also encouraging. The overall number of potential open breeding sites in Ilala was reduced by 76% 5 months after the campaign finished. In terms of vector control, this method of source reduction was extremely cost effective when compared to repeated treatments with pyriproxyfen. The complaint that latrines fill up more quickly as a result of receiving the sullage water is not supported by data on emptying frequency from the remaining households.

Entomological results indicated different degrees of success of the interventions against adult mosquito densities in the two study areas. The high density of adult mosquitoes in Mikocheni was reduced substantially by EPB during the dry season and, as the importance of open sites increased at the onset of the rainy season, the adult mosquito density continued to be suppressed by pyriproxyfen. In Ilala a similar decrease was noted after EPB treatment in the dry season. However, at the onset of the rainy season, the mosquito density rose out of proportion to the number of open breeding sites present in the area, and treatment of these relatively few sites with pyriproxyfen had no impact on the density of mosquitoes. The peak density of mosquitoes during the rainy season corresponded with the time when all enclosed breeding sites contained EPB and all open sites were either eliminated or treated with pyriproxyfen. Block-by-block searches within the area failed to reveal further sites. We conclude from this that almost all the mosquitoes caught in our light traps originated from outside the study area, despite the 'barrier zone'. Admittedly, even after the barrier zone was treated, no part of the study area was more than 600 m from untreated areas. Lindquist *et al.* (1967) found that some *Cx quinquefasciatus* travelled up to 1 km and a 'great number' up to 600 m during dispersion studies in Rangoon. They suggest that an effective barrier zone to prevent immigration of mosquitoes in an urban environment ought to be about 1 mile wide. Evidence from mark–release studies in India showed that *Cx quinquefasciatus* was capable of flying up to 7 km in a densely populated rural area (Yasuno *et al.*, 1978).

Many of the adult mosquitoes caught in Mikocheni following intervention have originated from undiscovered sites (open and enclosed) within the study area; systematic searching was hampered by the scattered lay-out of housing. Immigration was apparently less of a confounding factor in Mikocheni because the area was surrounded by an estate of housing connected to the mains drainage system, and was therefore to some extent isolated from other sources of *Cx quinquefasciatus*.

The results presented here show that an enclosed breeding site treated with EPB does not produce mosquitoes until the pit is emptied, whereas an open site treated with pyriproxyfen produces no mosquitoes for up to 3 months, depending on the season. However, in order to guarantee a worthwhile reduction in mosquito density, the area chosen must either be isolated from surrounding *Cx quinquefasciatus* breeding sites or cover a large enough area to ensure immigration of mosquitoes does not swamp the control effect. The tools for effective long-term *Cx quinquefasciatus* control are now available, but their full potential will not be realized until sustainable systems for implementing control programmes are developed.

The main practical limitation of EPB technology is that the benefit to the community, i.e. relief from mosquito biting, will only be perceived if the vast majority of breeding sites are treated over a large area. If treatment of enclosed on-site sanitation systems becomes the responsibility of the individual household, then those who do treat their pits may not perceive any benefit because of biting by mosquitoes derived from the pits of neighbours who neglect to do so (Stephens *et al.*, 1995). The third paper in this series will be concerned with social and economic aspects of mosquito control relevant to the planning of future large-scale control operations.

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