Journal of Tropical Medicine and Hygiene 1980, **83**, 165–171

The urban mosquitoes of Suva, Fiji: seasonal incidence and evaluation of environmental sanitation and ULV spraying for their control

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Introduction

Several major outbreaks of dengue or dengue-like illnesses have been reported in Fiji during the years 1885, 1930, 1944, 1971 and 1975 (Reed *et al.* 1977). *Aedes aegypti* (Lin) has been shown to be the principal dengue vector, while *Aedes pseudoscutellaris* (Theo), known only in Fiji, has been suspected (Maguire *et al.* 1974). In addition, *Ae. pseudoscutellaris,* and to a lesser degree, *Culex quinquefasciatus* (Say) (= *fatigans* Wiedemann) are vectors of non-periodic Bancroftian filariasis in Fiji (Symes 1960b). These mosquito vectors are present in the urban areas of Fiji (Reed *et al.* 1977, Suzuki & Hirshman 1977).

Many studies have shown that the primary source of urban *Aedes aegypti* breeding is artificial containers, domestic water storage receptacles being the most important (Chan *et al.* 1971, Gould *et al.* 1971, Suzuki & Hirshman 1977, Tonn *et al.* 1969). *Culex quinquefasciatus* breeds predominantly in water with high organic content including drains (Rajagopalan *et al.* 1975), pit latrines (Symes 1960b) and septic tanks (Buxton 1928). Studies have not been performed to determine the urban habitats of *Aedes pseudoscutellaris,* although it is known to breed in artificial containers (Symes 1960a).

There has been a great deal of discussion regarding urbanization and mosquito control. The conclusions state that environmental sanitation through source reduction should be the principal method of control. A piped water supply and regular garbage removal, as well as legislation, are requirements of this type of control programme (Chan 1973, Gratz 1973, MacDonald 1978). The major urban centres in Fiji have these requirements, yet the urban mosquito populations are high (Suzuki & Hirshman 1977) and dengue epidemics are occurring.

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A project in Suva, the capital of Fiji with a population of 63 628 (1977 population census) began in May, 1978. Its objectives were to: assess the seasonal incidence of urban mosquitoes; determine their breeding sources; evaluate means of reducing them through environmental sanitation.

In April, 1979, indications were that a dengue epidemic was occurring. The epidemic was later confirmed to be not dengue, but Ross River Fever (Mataika 1979). Consequently, emergency operations were conducted for the control of dengue vectors, which included ULV spraying of major urban areas for *Aedes* mosquitoes. This paper reports on the findings of the project and on the effects of the ULV spray program on the mosquito population in Suva.

Materials and methods

Study area

The study area consisted of two adjacent transects in the Toorak ward of Suva. The housing in this lower to middle-class area consisted of three storey apartment buildings, multiple ground level blocks and many single dwelling homes. One transect was designated the 'clean-up' area and the other, the 'control' area. The former contained 42 premises and was 275 m^2. The latter contained 35 premises and was 125 × 275 m.

Both the clean-up and control areas had a piped water supply, regular garbage removal (three times per week) and were visited by the Suva City Council health inspectors approximately

0022–5304/80/0800–0165 $02.00

three to four times a year. The majority of houses were connected to a city sewerage system except for 13 houses in each transect. Each of these 26 houses had their own septic tank installation.

Population monitoring

Larval surveys

Breeding sources were sought out at each premise. Ten larvae were removed from each container, placed in a labelled vial and brought to the laboratory for identification. The sampled container with the remaining larvae was always replaced in its original position. The number of containers with water, both positive and negative, were noted for each premise. These surveys did not include septic tanks.

Surveys were not conducted as often in the control area as in the clean-up area. It was felt that the presence of the survey teams might influence the sanitary habits of the residents.

Ovitraps

Twenty-five ovitraps were set out in a grid pattern in each of the two transects. Distances among ovitraps varied between 25 and 55 m. Ovitraps consisted of a black plastic cup (11 cm high × 7.5 cm diameter) half filled with tap water (approx. 150 ml). Each contained a hardboard paddle (13 × 2 cm) placed diagonally inside the cup with its rough surface facing upwards. Both ovitraps and paddles were numbered.

Paddles were removed twice weekly (at 4– and 3–day intervals) and replaced with new ones having the corresponding number. To make certain that no egg transfer occurred during transport to the laboratory each paddle was wrapped in a separate plastic bag. Water in the ovitraps was replaced weekly to ensure that breeding did not take place.

In the laboratory paddles were kept submerged for 2 weeks in individual plastic cups (6 cm high × 9.5 cm diameter) containing approximately 220 ml of water with two to three grains of baker's yeast added. Emerging larvae were identified as soon as they reached third or fourth instar. Some paddles were left submerged for an extra week in order to determine if more eggs would hatch out.

Paddles were prepared for reuse by submerging them in boiling water for 30 min, brushing them in running water and then setting them out to dry.

Adult landing rates

Landing rates were taken just prior to, during and up to 2 months following the ULV spray operation. Six stations were set up in each of the two transects. A battery operated aspirator was used to catch all the mosquitoes that landed on a human bait, naked to the waist, during a 10-min period at each station. All landing rates were taken between 09.00 and 12.00 h.

Septic tanks

Small wire framed cages covered with cotton netting (15 × 15 × 15 cm) were placed on the terminal air vents in premises that used septic tanks. Cages were checked for the presence of adults 1 day and 7 days later in the early morning. In addition, breeding in septic tanks was determined by taking dip samples in tanks outside the study area when they were opened up for bailing by the City Council Health Department.

Environmental sanitation

Between 21 and 22 February 1979, the clean-up transect was thoroughly cleared of mosquito breeding sources. This work was carried out by hired labourers moving from premise to premise placing all tins, bottles, coconut shells, etc. into large paper bags. These bags were later removed by the city garbage collectors. Sand was placed in receptacles that were permanent or too large to remove. Later, sand was placed in the water saucers used for potted plants. Overgrown brush and grass was also cut.

Pamphlets and circulars were distributed to the residents of the section by a health inspector. These contained information and pictures on breeding areas in and around the home and the actions necessary to keep them mosquito free.

Following the clean-up, the area was inspected monthly. All breeding containers were pointed out to the residents and destroyed whenever possible. Residents were urged to keep their premises clean. Notes were kept of the breeding places and any instructions given to the residents. In so doing, repeated offenders were warned of the legal consequences if immediate action was not taken to rectify the situation.

Insecticide spray

During the last 3 weeks of May 1979, Suva was sprayed for adult mosquitoes. Both the control and clean-up transects were sprayed on 12 and 30 May.

A truck mounted LECO ULV sprayer dispersing 95% malathion at a rate of 56 ml/min was used throughout the spray operation. The truck proceeded at 8 km/h with the nozzle pointing to one side. The vehicle covered both sides of every street. Approximately 35 min was spent spraying the whole study area during each spray operation.

Results

Seasonal incidence

Larval surveys

The surveys revealed that the following mosquito species were breeding in the study area: *Ae. pseudoscutellaris*, *Ae. aegypti*, *Cx. quinquefasciatus* and *Cx. annulirostris* Skuse. Figures for the larval incidence of these four species were combined to give a total Container*, Premise† and Breteau‡ Index (CI, PI and BI, respectively) for each of the control and clean-up areas during the period between May 1978 and August 1979 (Figure 1).

The species found in the largest numbers was *Ae. pseudoscutellaris,* followed by *Ae. aegypti.* Breeding of both species reached a peak in May, 1979 (Figures 2 & 3). *Cx. quinquefasciatus* showed no seasonal trend with the CI ranging between 0–6% ($\bar{X}$ =2.1) and BI ranging between 0–14% ($\bar{X}$ = 8.6%). On the other hand, *Cx. annulirostris* did show a seasonal variation and was more prevalent between May and July 1979. The CI for *Cx. annulirostris* during that period ranged between 0–4% ($\bar{X}$ = 1.3%) and the BI between 0–14% ($\bar{X}$ = 5.2%). For the period between May 1978 and April 1979, the CI ranged from 0–1% ($\bar{X}$=0.1%) and the BI, 0–3% ($\bar{X}$= 0.4%).

Ovitraps

Eggs of *Ae. aegypti* and *Ae. pseudoscutellaris* were found in the ovitraps, the latter being more prevalent. The ovitrap monitoring results are summarized in Figure 4. Egg deposition was highest for *Ae. pseudoscutellaris* in June, 1978 and January 1979, while a rise in oviposition for *Ae. aegypti* occurred between March and May 1979. It can be seen that the *Ae. pseudoscutellaris* January peak coincided with an increase in rainfall. Conversely, oviposition was lowest between the months of July and October 1978 when temperature and precipitation were at a minimum for the year. However, during this same four month period, the percentage of ovitraps found positive for *Ae. pseudoscutellaris* remained high (Figure 4).

An average of 6.4% (range = 0–12%) more *Ae. pseudoscutellaris* and 5.2% (range = 0–22%) more *Ae. aegypti* larvae emerged when paddles in the laboratory were left submerged for 1 extra week. This indicates that the majority of eggs laid on the paddles hatched during the initial submerged period of 2 weeks.

Breeding habitats

All species were found breeding most often in miscellaneous containers (Table 1), the majority of which were discarded tin cans and plastic food containers. Other breeding places found under the miscellaneous category included coconut shells, old motor parts and, least of all, ground pools. Plant containers ranked second in importance for *Ae. aegypti* and *Ae. pseudoscutellaris* breeding. Saucers and basins filled with water to keep the soil in potted plants moist were a very attractive oviposition site. Two other common breeding places of *Ae. aegypti* were tyres and flower vases.

Adults of *Cx. quinquefasciatus* were present in 36% of the cages placed over septic tank terminal air vents (n = 20). Larval sampling in septic tanks showed *Cx. quinquefasciatus* to be present in 50% of the tanks (n = 22).

Environmental sanitation

Effects on the vector population

Effects of the clean-up and of the five subsequent monthly inspections on the larval indices are shown in Figures 1, 2 & 3. These control measures reduced the combined BI by 75%, the combined PI by 58% and the combined CI by 69%. During this same period in the control area, the combined BI rose by 112%, the combined PI by 50% and the combined CI by 78% (Figure 1). This marked reduction in breeding of *Ae. pseudoscutellaris* was not so pronounced in that of *Ae. aegypti* (Figures 2 & 3).

Adult activity, as measured by the ovitrap monitoring system, was not affected by the environmental sanitation (Figure 5).

Expenditures

Details of the clean-up operation are summarized in Table 2. Approximately 0.62 man-hours (supervision included) per premise was spent on garbage collecting, 0.76 man-hours/premise for

*Per cent of water-holding containers positive for larvae.
†Per cent premises with breeding.
‡Number of positive containers per 100 homes.

brush cutting and 0.19 man-hours/premise for education. Follow-up inspections required approximately 0.33 man-hours/premise.

Insecticide spray

Effects on the vector population

Figure 5 demonstrates the results of ULV spraying on adult activity, as measured by the ovitrap monitoring system. The insecticide immediately caused a sharp decline in the adult population of *Ae. pseudoscutellaris,* however, the population tended to recover quickly. Adult landing rates, taken before and after spraying, also confirmed these points. Landing rates were reduced by 50 to 100% for approximately 1 week. Effects of

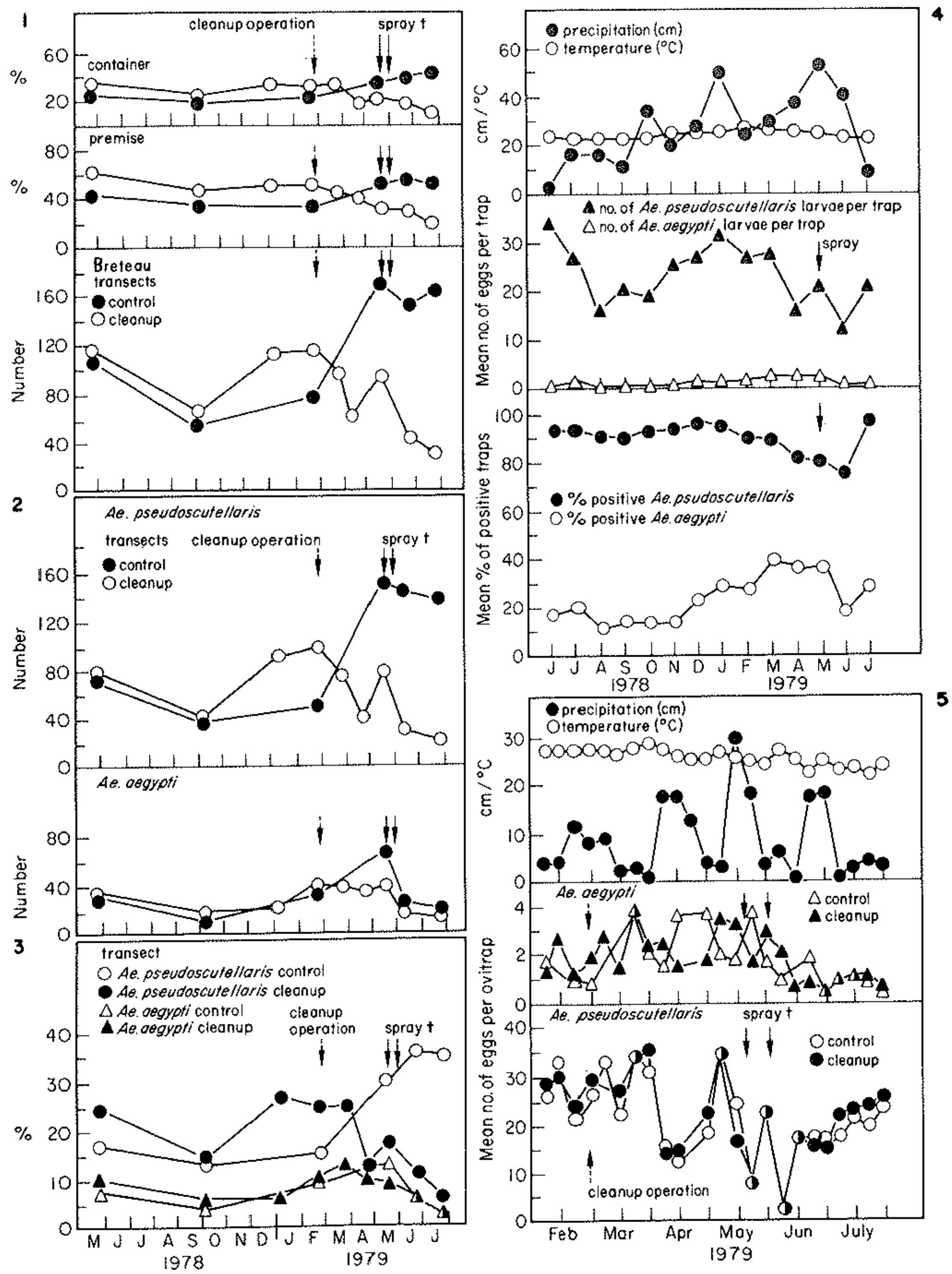

Table 1. Percentage incidence* of mosquito breeding in various habitats in an urban transect in Suva, Fiji

	Flower vase	Drum	Plant container	Tyre	Misc.
Ae. aegypti	17	5	22	18	39
Ae. pseudo-scutellaris	4	2	26	7	61
Cx. quinque-fasciatus	0	12	4	4	80
Cx. annuli-rostris	0	0	0	37	63

*Calculated on the basis of total number of habitats found positive for each species.

the spray on *Ae. aegypti* are not as clear, for throughout the landing count experiments very few mosquitoes (0–2.5) were landing per man-hour.

Spray effects on the larval indices are shown in Figures 1, 2 & 3. Unfortunately, a control, non-sprayed area, could not be kept, as the spray programme was initiated to reduce the mosquito population throughout Suva in the light of the Ross River Fever epidemic.

Expenditure

During the two insecticide applications, approximately 26 ml/premise of 95% malathion was used. Roughly 0.02 man-hours (1.2 min) were spent spraying each premise. Maintenance of the spray equipment and the time taken to refill the sprayer, etc. are not included in this figure.

Table 2. Summary of environmental sanitation measures in an urban transect in Suva, Fiji

No. of premises in study area: 42
No. of premises with garbage removed: 27 (64%)
No. of premises with grass and shrub cutting: 11 (26%)
No. of premises with tyres removed: 4 (9%)
No. of premises with miscellaneous sand fill: 5 (12%)
No. of premises with plant container-flower vase warnings: 10 (24%)

Materials used
10 buckets of sand
41 empty cement bags
50 mosquito prevention pamphlets and circulars

Garbage removed
41 bags of tin cans and miscellaneous containers (appx. 1.32 cu. m.)
8 tyres

Man hours

Labour:	
Garbage collecting	20 h
Brush cutting	25 h
Total	45 h
Educational:	
Distribution of pamphlets and circulars and explanation to residents (Health Inspectors): 8 h	
Supervision:	
Project leader	13 h
Grand total	66 h

Discussion

The dengue epidemics of 1971 and 1975 occurred between February and September (Maguire *et al.*

Figure 1. Fluctuations of combined larval indices for four mosquito species* between May 1978 and August 1979 in two adjacent transects in Suva, Fiji. **Aedes pseudoscutellaris, Ae. aegypti, Culex quinquefasciatus* and *Cx. annulirostris.* †Spraying was carried out in both control and clean-up transects.

Figure 2. Fluctuations in the Breteau Index of *Aedes aegypti* and *Ae. pseudoscutellaris* between May 1978 and August 1979 in two adjacent study transects in Suva, Fiji. †Spraying was carried out in both control and clean-up transects.

Figure 3. Fluctuations in the Container Index of *Aedes aegypti* and *Ae. pseudoscutellaris* between May 1978 and August 1979 in two adjacent study transects in Suva, Fiji. †Spraying was carried out in both control and clean-up transects.

Figure 4. Monthly averages of percent positive ovitraps and the number of eggs laid per ovitrap* for *Aedes aegypti* and *Ae. pseudoscutellaris* in relation to rainfall and mean temperature in Suva, Fiji‡. *No. of larvae eclosing within 14 days. ‡ 50 ovitraps were monitored twice weekly.

Figure 5. Average weekly number of eggs laid per ovitrap* for *Aedes aegypti* and *Ae. pseudoscutellaris* in relation to rainfall and mean temperature in two adjacent transects in Suva, Fiji‡. *No. of larvae eclosing within 14 days. ‡25 ovitraps in each transect were monitored twice weekly. †Spraying was carried out in both control and clean-up transects.

1974, Reed *et al.* 1977). During this same period in 1979, when the population of *Ae. aegypti* was at its highest, a few cases of dengue were reported (Mataika 1979). This indicates that past epidemics may have occurred when *aegypti* populations were at their peak for the season, and that the *aegypti* population during 1979 was not large enough for an epidemic to occur.

Increased incidence of *Ae. aegypti* also coincided with the Ross River epidemic which occurred between the end of April and the beginning of June, 1979 (Mataika 1979). It is not known which species in Fiji acts as a vector, although *Cx. annulirostris* and *Ae. vigilax* (Skuse) were shown to transmit the virus in Queensland (Kay *et al.* 1975). Increased breeding of *Cx. annulirostris* did occur within the study area during the epidemic period, but its incidence was low throughout the study. Since this species is capable of breeding in many habitats including running water and ponds (Belkin 1962), important breeding sources may have been present outside of the study area.

Larval indices in the clean-up transect decreased after the clean-up while those in the control area increased. It can be deduced that the environmental clean-up and five subsequent monthly inspections reduced the combined BI of the clean-up area by 88%, the combined PI by 72% and the combined CI by 83% (Figure 1). Although the reductions in the larval indices of *Ae. aegypti* were not as pronounced, the BI was 57% lower in the clean-up area than in the control area 3 months after the clean-up.

Even though the majority of breeding places were destroyed during the clean-up and larval indices were lowered considerably, the adult population, as measured by the ovitrap monitoring system, did not decrease. Consequently, it may be concluded that the adults ovipositing in this transect had immigrated from adjacent areas. This in turn indicates that grass and shrub cutting failed in deterring adults from immigrating into the transect.

Although the clearing of overgrown brush did not deter adult immigration, these cleared areas are less likely to accumulate discarded containers and other rubbish. Consequently, this procedure should be included in mosquito control campaigns.

The value of providing labour for collecting and destroying breeding containers from compounds appears to be questionable. Since no special equipment was utilized, this work could, in effect, have been easily carried out by the local homeowners themselves. Furthermore, one month after the clean-up, the number of potential breeding sites had only been reduced by 25%; newly discarded containers replaced ones that had been previously removed. Following each monthly inspection, the larval indices dropped measurably (Figure 1). Therefore, it can be seen that the major factor that contributed to the lowering of the larval indices was the vigilant and thorough monthly inspections. It must be pointed out that during these inspections, the public was asked to cooperate for its own benefit and no written notices or fines were issued.

These inspections, if carried out thoroughly and under proper supervision (especially between the months of October and July) should reduce the breeding of urban mosquitoes to a tolerable level. Yearly clean-up campaigns in which some labour was provided for destroying more permanent breeding areas (e.g. sand fill and screening of septic tank air vents) would also contribute to lowered breeding, but enforcement of the law and surveillance through house to house inspections should receive priority.

Ground applied ULV spray of malathion resulted in a 50–100% reduction in the adult population of *Ae. pseudoscutellaris* for a period of approximately one week (Figure 5). On the other hand, the first spray did not affect the population of *Ae. aegypti.* Following the application of the second spray, oviposition by *Ae. aegypti* decreased and it remained low throughout the rest of the study. The number of eggs laid in ovitraps during this period is comparable to the numbers laid during the period between August and November of 1978 (Figure 4). This suggests that the decrease in egg deposition may be due to the natural seasonal decline in the population.

Application of malathion appears to have had little effect on the larval indices of *Ae. pseudoscutellaris* (Figures 2 & 3). Even though larval indices of *Ae. aegypti* were lowered after the spray, no conclusions can be made as controls were not kept. These lowered larval indices could reflect a seasonal trend and not be due to the insecticide, as pointed out in the oviposition monitoring study.

Application of adulticides, without a larviciding or an environmental sanitation programme can have little lasting effect on the vector population. Also, susceptibility tests should be carried out at regular intervals in order to determine if any resistance has been acquired.

Acknowledgements

The authors wish to extend their thanks to Dr J. Senilagakali, Permanent Secretary for Health, Fiji, for his permission to publish this report. We are also grateful to all those in the Ministry of Health and the Suva City Council Health Department who contributed to the study. Special thanks are due to the following: Messrs I. Latedreketi, G. Prakash, P. Prasad and U. Chand of the Vector Research Unit.

Appreciation is also given to Dr M. Laird, RUVP, Newfoundland, Canada, for his support and for acting as supervisor under the CIDA Award requirements.

This study was supported by a Canadian International Development Agency Award to MSG and MKT and by funds from South Pacific Commission and WHO/TDR Research Grants to JSP.

Summary

Larval surveys and oviposition traps were used to monitor urban mosquito populations in two adjacent transects in Suva, Fiji between May 1978 and August 1979. Populations of *Aedes aegypti* and *Ae. pseudoscutellaris* fluctuated seasonally with changes in rainfall, the latter species being most prevalent throughout the year. Populations of these two species were highest between December and July and lowest between August and October. Larval populations of *Culex quinquefasciatus* did not show a seasonal variation and larval populations of *Cx. annulirostris* were too low for any conclusions to be made. All species were found breeding most often in miscellaneous containers, with tyres, plant containers and flower vases also being important sources for *Ae. aegypti* breeding. Through environmental sanitation the Breteau Index for all species was reduced by 88%; Premise Index by 72% and the Container Index by 83%, when compared to a control area. ULV applied malathion was effective in temporarily reducing *Ae. pseudoscutellaris* populations from 50–100%. Effects on *Ae. aegypti* were inconclusive. It is concluded that through enforcement of the existing laws and strict monthly surveillance during the periods of highest seasonal density, urban *Aedes* and *Culex* populations can be maintained at an acceptable level.

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