Article

Integrated Control of Peridomestic Larval Habitats of *Aedes* and *Culex* Mosquitoes (Diptera: Culicidae) in Atoll Villages of French Polynesia

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ABSTRACT An integrated larval mosquito control program was carried out in Tiputa village on Rangiroa atoll of French Polynesia. Mosquito abundance before and after treatment was compared with the abundance in an untreated village. Mosquito larval habitats consisted of large concrete or polyurethane cisterns, wells, and 200-liter drums. Depending on the target species, larval habitat category, its configuration, and purpose (drinking consumption or not), abatement methods consisted of sealing the larval habitats with mosquito gauze, treating them with 1% Temephos, covering the water with a 10-cm thick layer of polystyrene beads or introducing fish (*Poecillia reticulata* Rosen & Bailey). All premises of the chosen village were treated and a health education program explained basic mosquito ecology and the methods of control. A community health agent was trained to continue the control program at the end of the experiment. Entomological indices from human bait collections and larval surveys indicated that mosquito populations were reduced significantly, compared with concurrent samples from the untreated control village, and that mosquito control remained effective for 6 mo after treatment. Effects of the treatment were noticed by the inhabitants in terms of a reduction in the number of mosquito bites. In the Polynesian context, such control programs may succeed in the long-term only if strong political decisions are taken at the village level, if a community member is designated as being responsible for maintaining the program, and if the inhabitants are motivated sufficiently by the mosquito nuisance to intervene.

KEY WORDS *Aedes, Culex,* mosquito control, biting index, community education, Polynesia

In French Polynesia, in addition to the serious nuisance problem caused by *Aedes* and *Culex* mosquitoes, dengue virus and subperiodic *Wuchereria bancrofti* (Cobbold) are transmitted to humans. Four abundant mosquito species can be distinguished. *Aedes aegypti* (L.) is the main vector of dengue viruses, whereas *Ae. polynesiensis* Marks, which transmit dengue viruses, also is the main vector of *W. bancrofti* and *Dirofilaria immitis* Leidy, the causative agent of canine filariasis. *Culex quinquefasciatus* Say, a minor vector of *W. bancrofti,* is mainly a nuisance species, along with *Culex annulirostris* Skuse, which is also a vector of *D. immitis.* Both *Aedes* species have a diurnal activity, whereas the *Culex* species bite at night.

On atolls, unlike the mountainous islands of Polynesia, there is no running water, no streams or rivers. The only freshwater sources are wells and ponds dug down to the water table, and rainwater collected from the roofs of houses and stored in various receptacles. As such, village mosquito larval habitats are mostly artificial containers such as concrete or polyurethane cisterns and 200-liter drums used to collect rainwater, wells, and ponds. These sites are easy to locate and can be counted reliably, treated, and monitored.

Results presented herein describe the experimental integrated control and follow-up of all larval habitats in a representative atoll village using physical, chemical, or biological techniques adapted to the various types of habitats and mosquito species present and reinforced by community education and participation. Our experiment was the first attempt of village scale-integrated mosquito control on an atoll on French Polynesia. Such mosquito control programs are not standard activities in French Polynesia where no control currently exists, except during dengue outbreaks when adult mosquito control is achieved by adulticide applications. The aim of our experiment was to develop mosquito control methodology that would be generally applicable to atoll villages. Moreover, the ecology of peridomestic mosquitoes are not well known in atoll villages, and our experiment was designed to describe mosquito larval habitats, adult nuisance levels, and the awareness, acceptability, and

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participation of the community in the control methods selected.

Materials and Methods

Study Villages. Rangiroa atoll (15.5° S, 147.5° W) in the Tuamotu Archipelago ≈300 km northeast of Tahiti was chosen for study because it is the only French Polynesian atoll that has two distinct villages: Avatoru and Tiputa. Tiputa was treated for mosquitoes, whereas Avatoru was kept untreated as a control. Tiputa and Avatoru are located 10 km apart, on two different islets separated by a large inlet, which enables water passage between the sea and the lagoon. As such, the two villages were isolated in regard to their mosquito fauna.

Most of the atoll human population inhabits these two villages. Tiputa contained 150 premises in which 500 inhabitants lived, whereas Avatoru has 900 inhabitants in ≈250 premises. The two villages had similar ecological environments as well as similar population densities. Generally, each premise consisted of one house surrounded by a garden of several 100 m^2.

The climate is tropical maritime, with mean temperature varying between 24.5 and 29.3°C. Annual precipitation is ≈1,800 mm, with rainfall mainly falling between November and March.

Identification of Larval Habitats and Mosquito Species. Before intervention, Tiputa was surveyed to locate and count all mosquito larval habitats, and to identify the various mosquito species and determine their relative abundance. Larval samples were taken by dipping in each positive site with a 300-μm mesh plankton net, and samples were examined under microscope for species identification. Because of the difficulty sampling some water tanks and cisterns, netting could not be quantified. Therefore, analysis was based on the presence or absence of larvae, with four abundance categories: no larvae, low (<10 larvae), medium (<100 larvae), and high (>100 larvae). This survey served as a baseline upon which to organize village treatment.

Methods of Control and Village Treatment. The methods of control were selected in accordance with the type of larval habitat, the use of the water by inhabitants, and the characteristics of the method (robustness, duration, cost, and ease of implementation and maintenance).

Poecillia reticulata Rosen & Bailey were released into open wells, water holes, and ponds as recommended by Lardeux (1992). Fish were not released into water stored for human consumption. A concrete fish pond was built as a reservoir to provide a source for future fish introduction into newly dug wells or ponds. Physical control consisted of sealing cisterns with metal mosquito screening on overflows and rain pipes or spreading polystyrene beads (>10 cm deep) in wells and cisterns when construction permitted. Polystyrene beads (BASF, Styropor P006, Ludwigshafen, Germany) were expanded at the time of the treatment by heating them in boiling water for 7 min. Chemical control was used only when none of the above methods were appropriate. Temephos (Abate 1% granules, AgrEvo France, Saint-Aubin), an organophosphate insecticide used routinely in drinking water (Hervy and Kambou 1978), was applied at the rate of 1 mg/liter. Our objective was to provide mosquito control for 6 mo without additional intervention, a goal that has never been reached in any Polynesian environment.

Health Education. A survey was carried out in Tiputa 6 mo before treatment to determine population knowledge, perception, and behavior related to mosquito nuisance and transmitted pathogens. Most Tiputa premises were visited, with one person per premise being asked 15 questions (86 questionnaires answered). Community education was carried out just before treatment on the basis of the results of this questionnaire. During house visitations, basic mosquito ecology, the aim of the control methods chosen, and the way that the control methods perform was described to each resident. A small leaflet containing this information both in French and Tahitian was given to each family and distributed at each of the three food stores, the post office, and the townhall. Permission for our team to treat each premise was requested from each head of household. A technician from the study village was trained in mosquito control techniques to continue surveillance after treatment and to help residents control larval habitats.

Table 1. Mosquito habitats and mosquito species collected in Tiputa Village before control

	Cisterns	Wells	200-liter drums	Others
Total counted	201	111	38	13
% sampled	87.9	88.4	100.0	100.0
% negative sites	18.7	34.8	24.0	46.2
% positive sites	81.3	65.2	76.0	53.8
% positive with <10 larvae	36.9	33.3	38.5	—
% positive with <100 larvae	34.2	22.7	19.2	—
% positive with >100 larvae	10.7	8.0	19.2	—
% with *Ae. aegypti*	100.0	75.5	100.0	0.0
% with *Ae. polynesiensis*	0.0	24.4	0.0	0.0
% with *Cx. quinquefasciatus*	0.0	11.1	5.3	0.0
% with *Cx. annulirostris*	0.0	11.1	2.6	0.0
% with *Cx. roseni*	0.0	4.4	0.0	0.0

The "Others" category corresponds to usual peridomestic sites such as cans, tins, old tires, and various small containers.

Table 2. Treatment of permanent mosquito habitats in Tiputa Village

	Total treated	% Sealed up	% with larvivorous fish	% with polystyrene beads	% with chemical insecticide	% with no intervention
Cisterns	201	57.7	4.5	4.5	25.4	7.9
Wells	111	10.8	36.9	46.8	1.8	3.6
200-liter drums	38	5.2	0.0	0.0	94.8	0.0

Larvivorous fishes were *Poecilia reticulata.* The chemical insecticide used was Temephos (Abate 1% granules) at the dose of 1 mg (AI)/liter.

Evaluation of Treatment. *Mosquitoes.* Mosquito populations in Tiputa and Avatoru were compared on five occasions: at 1 yr, 6 mo, and just before treatment, and at 6 wk and 6 mo after treatment. Mosquito populations were sampled in 30 premises chosen at random, 15 in Tiputa and 15 in Avatoru. Mosquito larvae were collected using a 300-μm mesh plankton net and larval habitats classified using our four-category semi-quantitative abundance scale. Adult day-biting mosquitoes (i.e., *Ae. aegypti*) were collected at human bait by aspiration for 15 min per premise. Attempts were made to collect night biting *Culex* by means of CDC light traps, but catch was too low for analysis.

Community Acceptance. A second questionnaire (25 questions; 48 questionnaires answered) was carried out 1 mo after treatment to measure the population's improvement in understanding basic mosquito ecology, the acceptability of the control methods, and the perception of the treatment effects.

Statistical Analysis. Before statistical analysis, counts of adult *Ae. aegypti* were transformed to log $(x + 1)$ to normalize the distribution and stabilize variances. Biting indices were analyzed by analysis of variance (ANOVA) or by t-tests to compare differences between villages and before and after treatment. Chi-square tests or exact Fisher tests were used to compare proportions.

Results

Identification of Mosquito Species and Larval Habitats. Artificial containers to store rainwater consisted of large concrete cisterns up to 30-m^3 capacity, polyurethane cisterns of several m^3, and plastic or metal 200-liter drums. These sites, including wells, sometimes were sealed, simply covered with sheet-metal or planks, or open. In general, rainwater was used for human consumption (e.g., drinking, cooking, showers), whereas brackish water from the wells is used for washing and watering gardens. The mean volume of cisterns was 19.3 m^3, with 11.3 m^2 of surface. The total volume of rainwater stocked in the cisterns was estimated to be 3,000,000 liters for the whole village. Because litter was efficiently collected in Tiputa, few small peridomestic larval habitats such as old tires or cans were found.

Five mosquito species were recorded in both villages: *Ae. aegypti, Ae. polynesiensis, Cx. quinquefasciatus, Cx. annulirostris,* and *Culex roseni* Belkin. The positive habitats found in Tiputa, the colonizing mosquito species, and their relative abundance are summarized in Table 1. In this Table, the sum of the percentage of sites positive for each species (i.e., sites where at least one mosquito larvae was sampled) was >100%, because sites often were colonized by more than one species. Most sites in Tiputa were sampled (cisterns and wells ≈88%, 200-liter drums and other sites 100%). *Ae. aegypti* was the most prevalent and numerous species. *Ae. polynesiensis* was common in wells. *Culex* sp. were present only in some wells and 200 liter drums.

Treatment. The control techniques applied in Tiputa were summarized in Table 2. Most cisterns were sealed with metallic mosquito gauze. Some previously were sealed, but not enough to intervene. In some old cisterns not used for drinking water, *Poecillia* fishes were introduced. Polystyrene beads mostly were used to control larvae in covered wells. Open wells were treated with larvivorous fishes, whereas most of the 200-liter drums were chemically treated with Temephos. All sites were treated within 1 wk by a team of six people.

Evaluation of Treatment. *Adult Mosquito Populations.* Adult catch in the control village of Avatoru remained similar over time, ranging from 2.67 to 5.75 females per collector per 15 min (ANOVA, $F = 0.79$; df = 3, 53; $P = 0.50$). In Tiputa there was a significant difference in the mean number of mosquitoes col-

Table 3. Mean number of biting *Aedes* per human per 15 min, and percentage of negative catches in the treated village of Tiputa and the control village of Avatoru, before and after treatment

Date/treatment	Tiputa (treated village)				Avatoru (control village)			
	No. of catches	Mean mosquito females	SD	% of negative catches	Nb. of catches	Mean mosquito females	SD	% of negative catches
6 mo before	15	2.53	2.97	20.0	15	4.13	4.76	6.7
Just before	15	1.87	2.83	20.0	15	2.67	4.98	20.0
6 wk after	15	1.20	1.52	53.3	12	5.75	6.63	33.3
6 mo after	15	0.47	0.92	73.3	15	4.60	8.13	33.3

Table 4. Percentage of cisterns with 0, <10, <100, and >100 mosquito larvae at each sampling occasion, before and after treatment, in the two villages of Tiputa (treated village) and Avatoru (untreated village)

Date	Village	No. of sites sampled	Cisterns with			
			No larvae, %	<10 larvae, %	<100 larvae, %	>100 larvae, %
12 mo before	Treated	19	26.3	42.1	21.1	10.5
treatment	Control	—	—	—	—	—
6 mo before	Treated	18	0	38.9	22.2	38.9
treatment	Control	20	15	25	55	5
Just before	Treated	19	42.1	31.6	26.3	0
treatment	Control	20	30	40	25	5
6 wk after	Treated	18	72.2	5.6	22.2	0
treatment	Control	15	13.4	33.6	46.6	13.3
6 mo after	Treated	19	84.2	10.5	5.3	0
treatment	Control	18	16.7	44.3	22.3	16.7

lected in Tiputa (ANOVA, $F = 5.05$; df = 3, 56; $P = 0.003$). A Tukey multiple range test indicated that the mean number of mosquitoes was significantly lower at 6 wk and 6 mo after treatment (Table 3). There were no differences between Tiputa and Avatoru 6 mo ($t = -0.62$, df = 28, $P = 0.53$) or just before treatment ($t = -0.41$, df = 28, $P = 0.68$). Mean catch was less in the treated village of Tiputa than in the control village of Avatoru 6 wk ($t = -2.25$, df = 28, $P = 0.03$) and 6 mo after treatment ($t = -2.55$, df = 28, $P = 0.01$). When tested by chi-square, the percentage of negative sites was not statistically different between the two villages at 6 mo, just before and 6 wk after treatment ($P = 0.30$; 1.00 and 0.51, respectively). However, 6 mo after treatment the percentage of negative samples was statistically greater in the treated than in the control village (73.3 versus 33.3%; $P = 0.03$).

Larval Mosquito Population. The percentage of cisterns and wells harboring high numbers of larvae decreased after treatment in Tiputa, but not in the control village (Tables 4 and 5). Concurrently, the percentage of sites with no larvae increased after treatment in Tiputa; 6 mo and just before treatment, these percentages were not different in Tiputa and Avatoru (cisterns: $P = 0.13$ and 0.43, respectively; wells: $P = 0.40$ and 0.80, respectively). One month and a half and 6 mo after treatment, the percentage of negative sites was significantly greater in Tiputa than in the control village of Avatoru (cisterns: $P < 0.05$ and $P < 0.05$; wells: $P = 0.05$ and < 0.05, respectively). The status of 200-liter drums was less clear, because few were used in Tiputa and therefore statistical comparison with Avatoru was not feasible (Table 6). However, these sites seemed to be the most difficult to control, because of their frequent filling and emptying by owners.

Community Awareness Before Treatment. In Tiputa, despite regular TV or radio spots, 34% of people thought that mosquitoes did not transmit disease agents, 7% do not know, and 13% mentioned other diseases such as tuberculosis, influenza, or gastritis. Almost 75% of people did not know if mosquito larval habitats existed on their premise and basic mosquito ecology was not well understood. Only 7% of the people did not suffer from mosquito bites, whereas 83% did at night as well as day. The perceived level of nuisance in Tiputa indicated that mosquito bites were numerous (Table 7). Most inhabitants (87%) used mosquito-coils for personal protection, whereas only 19% cleaned mosquito larval habitats (14% with an efficient frequency) and 4% used other means such as oiling the water surface.

Community Awareness Six Weeks After Treatment. Almost 75% of people understood the relationship between mosquitoes and disease, indicating an improvement after our door-to-door education and treatment program (Table 8). After treatment, fewer people perceived that they were bitten and the mean number of bites was reduced, indicating a strong impact of the treatment program on the perception of the mosquito nuisance by the inhabitants (Table 7). As such, 68% of people thought that "it was possible to reduce mosquito densities."

Considering the methods of treatment, 14% of people did not know exactly what had been done on their

Table 5. Percentage of wells with 0, <10, <100, and >100 mosquito larvae at each sampling occasion, before and after treatment, in the two villages of Tiputa (treated village) and Avatoru (untreated village)

Date	Village	No. of sites sampled	Wells with			
			No larvae, %	<10 larvae, %	<100 larvae, %	>100 larvae, %
12 mo before	Treated	16	50	12.5	31.3	6.2
treatment	Control	—	—	—	—	—
6 mo before	Treated	17	41.2	29.4	29.4	0
treatment	Control	10	20	20	20	40
Just before	Treated	16	37.5	25	31.3	6.2
treatment	Control	10	50	0	20	30
6 wk after	Treated	16	93.8	6.2	0	0
treatment	Control	10	60	0	10	30
6 mo after	Treated	17	100	0	0	0
treatment	Control	9	40	20	20	10

Table 6. Percentage of 200-liter drums with 0, <10, <100, and >100 mosquito larvae at each sampling occasion, before and after treatment, in the two villages of Tiputa (treated village) and Avatoru (untreated village)

Date	Village	No. of sites sampled	200-liter drums with			
			No larvae, %	<10 larvae, %	<100 larvae, %	>100 larvae, %
12 mo before treatment	Treated	8	37.5	25	0	37.5
	Control	—	—	—	—	—
6 mo before treatment	Treated	2	0	0	0	100
	Control	12	0	25	50	25
Just before treatment	Treated	3	0	0	33.3	66.7
	Control	22	13.6	22.7	27.3	36.4
6 wk after treatment	Treated	3	33.3	33.3	33.3	0
	Control	22	22.7	13.6	45.5	18.2
6 mo after treatment	Treated	4	75	0	25	0
	Control	23	0	43.5	34.8	21.7

premise to control mosquitoes (but 86% knew). 91% of people were satisfied with the control methods employed (and only 9% were not, mainly because of the use of Temephos in their cistern and the resulting bad odor of the water during a few days).

Discussion

In general terms, Tiputa villagers were well aware of the nuisance caused by mosquitoes, even if their knowledge of mosquito transmitted pathogens was partial. Health education developed their understanding of vector-borne diseases and methods to control mosquito larval habitats, so that the experiment in Tiputa was carried out with the full consent of the community. An efficient municipal rubbish collection program kept Tiputa free of potential *Ae. aegypti* larval habitats such as discarded tins, cans, old tires. This community hygiene was an important contribution to our experiment's success. Rubbish collection that removes small peridomestic larval habitats is common in French Polynesia, but rarely practiced effectively in other parts of the world (Kay 1986).

Integrated control in Tiputa clearly impacted the mosquito population. A significant reduction of the number of biting *Ae. aegypti* was observed, the number of negative larval habitats increased, and few larvae were encountered in the few positive larval habitats. Reduction of the mosquito population also was experienced by the inhabitants who reported that after treatment they did not use repellents or personal protection against mosquito bites. The impact on mosquito adult and larval populations clearly was observed when abundance in Tiputa was compared before and after treatment to untreated Avatoru. The experiment demonstrated that controlling mosquitoes in a French Polynesian village was feasible by simple, long lasting and relatively inexpensive methods. In Tiputa, the estimated cost of treatment was less than U.S.$20 per premise (total expenses for polystyrene beads, mosquito gauze, insecticide, and other material divided by the number of premises treated).

The most effective method was the introduction of polystyrene beads in wells. Such a technique has been employed successfully to control *Cx. quinquefasciatus* in cesspits of villages in Zanzibar (Maxwell et al. 1999), achieving a 65% adult mosquito reduction. In Tiputa, this technique was well accepted by inhabitants, because of its safety, nonpollutant action, and long lasting effect without maintenance. In general terms, it was the method of choice in all covered larval habitats where light was insufficient to permit fish introduction. Wherever *Poecelia* fishes thrived in open wells and ponds, they quickly eliminated mosquito larvae. This method of control has already proven its efficacy in atoll villages (Lardeux 1992). Six months after treatment, large populations of larvivorous fishes had developed in each site, showing a good adaptation to their new environment. However, inhabitants were not used to stocking new ponds from the fish reserve.

Some treatments were less successful. Some metallic mosquito screening used to seal cisterns was removed or accidentally broken and was not replaced. Most chemical treatments were not renewed, because of the bad odor of the active ingredient that lasted several days after treatment, despite the elimination of larvae from these sites, observed by the inhabitants. However, when cisterns were sealed correctly, effective control of mosquitoes was achieved. New cisterns can be constructed with sealed input and output sys-

Table 7. Percentage of responses before treatment (86 questionnaires answered) and after treatment (48 questionnaires answered) (Question: How many mosquito bites during the last 24 h?)

No. Bites	Before treatment, %	6 wk after treatment, %
0	2	10
1–10	29	48
10–20	8	28
>20	61	13

Table 8. Percentage of responses before treatment (86 questionnaires answered) and after treatment (48 questionnaires answered) (Question: Do mosquitoes transmit diseases?)

Response	Before treatment, %	6 wk after treatment, %
No	34	7
Yes (dengue and filariasis cited)	10	46
Yes (dengue or filariasis cited)	38	29
Yes (but false diseases cited)	13	5
Do not know	7	12

tems and such mechanical solutions were proposed to the villagers for future implementation.

Overall, 200-liter drums were the most difficult larval habitats to control because villagers rapidly used and replenished the water, thereby voiding simple long-term control methods. Covering these sites may be an efficient technique, but not all inhabitants understood that this cover must be permanent and only removed for short periods to gain access to the water.

Consolidation of the villagers' knowledge on mosquito ecology and control should be continued. Health education seemed to be the main key to success in this Polynesian environment. Most treatment failures were due to a lack of treatment maintenance at the premise level; even if villagers saw mosquito larvae reappearing on their premises, they did not intervene. Residents did not seem to be concerned and expected that our entomological team would repeatedly treat the village. This attitude is usual among French Polynesian inhabitants who are used to governmental solutions to their health problems. Therefore, the presence of a community health agent specialized in mosquito control may be a necessity in such situations. Unfortunately, the individual trained by our team did not maintain his role because of his lack of motivation in the long-term. It is clear that any Polynesian control program needs strong local political support that can act as a catalyst for promoting a responsible health community agent in charge of mosquito problems at a village level, as well as for interesting inhabitants in vector and nuisance mosquito control.

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References Cited

Hervy, J.–P., and F. Kambou. 1978. Village scale evaluation of Abate for larval control of *Aedes aegypti* in Upper Volta. WHO/VBC/78.694.

Kay, B. H. 1986. *Aedes aegypti:* why we can't control it? Arbovirus Res. Aust. 4: 139–142.

Lardeux, F. 1992. Biological control of Culicidae with the copepod *Mesocyclops aspericornis* and larvivorous fish (Poeciliidae) in a village of French Polynesia. Med. Vet. Entomol. 6: 9–15.

Maxwell, C. A., K. Mohammed, U. Kisumku, and C. F. Curtis. 1999. Can vector control play a useful supplementary role against Bancroftian filariasis? Bull. WHO 77: 138–143.

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