

Cost-Effectiveness of a Community-Based Approach Intertwined with a Vertical *Aedes* Control Program

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Abstract. We compared in a 5-year intervention study the cost-effectiveness of community-based environmental management intertwined with routine vertical *Aedes* control and of routine vertical control only. At baseline (year 2000), *Aedes* infestation levels and economic costs for vector control were comparable in intervention and control areas (house index, 2.23% versus 2.21% and US\$21 versus US\$24/yr/inhabitant, respectively). By 2004, house indices became 0.22% versus 2.36% and the costs were 29.8 US\$ versus 36.7 US\$/yr/inhabitant, respectively. The community cost made up 38.6% of the total economic cost in 2004 in the intervention areas against 23.5% in 2000. The average cost-effectiveness ratio for the intervention period 2001–2004, expressed as the societal cost incurred for the reduction (from baseline) of *Aedes* foci, was US\$831.1 per focus in the intervention areas versus US\$2,465.6 in the control areas. The intervention produced economic savings and health benefits that were sustained over the whole observation period.

INTRODUCTION

Dengue is a viral vector-borne disease that has become a major international public health problem in recent years. Dengue prevention depends to a large extent on control of the main vector, *Aedes aegypti*. This mosquito breeds in water-filled containers in the (peri-)domestic environment, and elimination of its varied larval habitats is a daunting and costly task. Community participation has been promoted as a venue to make *Aedes* control more sustainable by securing behavioral change at household and community levels.^{1–9} Some successful pilot experiences were reported,³ but their cost and cost-effectiveness have hardly been assessed,¹⁰ and their sustainability remains debated.^{8,9}

In Cuba, dengue prevention has been a political priority since 1981, and the vertical *Aedes* control program is well resourced. It is managed at the national level by the Ministry of Health (MOH), but room is left for operational decision making at more decentralized levels. Even though it attains adequate coverage of the whole island, the vertical *Aedes* control program does not succeed in keeping the *Aedes* indices always below target (house index < 1%) in all regions, and localized dengue outbreaks occurred in Santiago de Cuba in 1997¹¹ and in Havana City in 2000–2001.¹² From 2000 onward, the Cuban MOH has encouraged community-based environmental management to prevent dengue.^{13,14} Between 2000 and 2002, a pilot project in Santiago de Cuba coupled a community-based active participatory approach with the routine vertical *Aedes* control program.¹⁵ Significantly better results were obtained in terms of behavioral changes, entomologic indices, and cost-effectiveness than with the vertical *Aedes* control program alone.^{15,16}

Sustainability and cost-effectiveness over time are key issues in community-based *Aedes* control. The sustainability of the intervention in Santiago de Cuba was addressed by Toledo and others.¹⁴ The objective of this paper is to compare,

over a 5-year period, the cost-effectiveness of the community-based environmental management approach intertwined with the vertical *Aedes* control program to the cost-effectiveness of that program alone.

MATERIALS AND METHODS

Context. Santiago de Cuba is a city with 470,000 inhabitants in the east of Cuba. It is subdivided in nine health zones with a dense Primary Health Care (PHC) network of polyclinics and family medicine practices (staffed by doctors and nurses) and is fully covered by the vertical *Aedes* control program. A dengue epidemic struck the town in 1997,¹¹ and *Aedes* infestation has persisted ever since, with house indices between 1% and 5%, the highest on the island. This led, in 2000, to the launch of a community-based vector control project that was supported by an external research group from the Institute of Tropical Medicine “Pedro Kourí” in Havana. As intervention areas, the coverage areas of 20 family practices were purposively selected in three health zones, among the ones with the highest *Aedes* levels. The control areas consisted of an identical number of control practice coverage areas in three comparable health zones of the same municipality. The population in the intervention and control areas was 11,520 inhabitants (2,400 houses) and 10,920 (2,600 houses), respectively. The activities in the intervention and control areas are summarized below; a detailed description can be found in Toledo and others.^{14,15}

The vertical *Aedes* control program carried out the regular routine *Aedes* control activities in the intervention and the control areas. They consisted of entomologic surveillance and source reduction through periodic inspection of houses, larviciding (with temephos) of water-holding containers, selective adulticiding (with cipermethrine and clorpirifus) when *Aedes* foci were detected, providing health education, and enforcing mosquito control legislation through the use of fines.

In the intervention areas, a community-based environmental management approach was added to the routine vertical *Aedes* control program. Community working groups (CWGs) were set up to identify local health problems and needs and to subsequently elaborate and implement action plans related

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to *Aedes* control. These eventually included, among others, household level control of (peri-)domestic larval habitats, eliminating environmental risk in public areas, transforming garbage belts into vegetable gardens, repairing broken water pipes, sealing basements, and manufacturing water container covers. One CWG was formed in the coverage area of each family medicine practice. It incorporated formal and informal leaders and volunteers, as well as family practice staff (living within this neighborhood) and vertical *Aedes* control program staff. No financial incentives were offered to the members.

The routine vertical *Aedes* control program activities were stepped up from early 2001 onward in the light of a dengue outbreak in Havana. The intervals between house inspection cycles for larval control were reduced from 22 to 11 days, and defective water tanks were gradually replaced. In the control areas, additional measures were taken: blanket spraying was introduced for adulticiding in a radius of 150 m around detected *Aedes* foci, and the MOH intensified local information, education, and communication campaigns on dengue.

Time horizon and analytical perspective. The time horizon for this study covers 5 years. The project was prepared in 2000 (formative research and baseline assessment) and implemented in 2001–2002. External support was withdrawn early 2003. The community-based activities were sustained in the intervention area with local means during the follow-up period (2003–2004). We collected cost and effectiveness data in the intervention and control areas and compared the cost-effectiveness ratios during the respective periods. The analysis was carried out from the perspective of the MOH and of the society. In the latter perspective, we included the financial cost of the MOH and the economically valued contributions made by the community.

Data collection and analysis. *Costs.* We estimated the economic costs per fiscal year using the methodology proposed by Johns and others.¹⁷ Essentially, we split up recurrent and capital (for goods lasting > 1 year) MOH costs and treated the community cost as a separate category. The recurrent MOH costs included staff salaries (of the vertical *Aedes* control program staff and of Primary Health Care staff, but accounting only time spent during duty hours), supplies for larval control and spraying, training, social communication, and operating costs. The capital costs included vehicles and equipment. Information was extracted from bookkeeping records of the health zones and obtained through semi-structured interviews with health personnel and direct observation of the control activities. The community cost estimates the value of unpaid community work contributed by community leaders and household-members, but also by MOH staff participating in community activities during their free time. We estimated these contributions through interviews with all actors and valued them at the wage rate for similar work in the government sector.

The costs in Cuban pesos were standardized at 2000 constant prices using a GNP implicit deflator¹⁸ and were converted to \$US at the official 2000 exchange rate of 1 peso = 1 \$US. We calculated costs per inhabitant for each year by dividing the corresponding societal cost (adding recurrent, capital, and community costs), the MOH cost (subtracting the community cost from the economic cost), the vertical *Aedes* control program cost (subtracting from the MOH cost the primary health care costs, i.e., the salary cost of PHC staff for on duty time devoted to vertical *Aedes* control program activities), and the

community cost by the number of inhabitants in the control and intervention areas, respectively.

Effectiveness and cost-effectiveness. We used the larval indices and the number of *Aedes* foci reported by Toledo and others.¹⁴ We calculated the average annual number of foci before the intervention (1998–2000), during implementation (2001–2002), and follow-up (2003–2004) and over the period 2001–2004. The difference between the baseline averages and the averages for the subsequent periods constitute the effectiveness measure. The average cost-effectiveness ratio for a given period was calculated by dividing the yearly average costs by the corresponding effectiveness estimates. We calculated incremental cost-effectiveness by dividing the difference in total cost by the difference in effectiveness between the two strategies.

Willingness to pay for or to participate in Aedes control activities and observed household contributions. In 2004, we conducted a cross-sectional questionnaire survey in a random sample of 200 households each in the intervention and in the control areas. One adult per household was selected as respondent. To explore the willingness to pay for and to participate in activities for *Aedes* control, we used the methods described by Riera.¹⁹ The declared willingness was compared with the observed household contributions to vector control activities. The sample size was calculated to detect (with $\alpha = 0.05$ and 80% power) a difference of 15% or more in the proportions of respondents “willing to pay or participate” in both areas. The Fisher exact test and *t* test were used to compare the groups.

Ethical aspects. The study protocol was approved by the Ethical Committee of the Institute of Tropical Medicine Pedro Kourí, Cuba, and by the national and local health authorities. Community approval was secured during meetings with the community before project implementation. Informed consent was obtained for the interviews conducted with individual actors.

RESULTS

Cost analysis. During the baseline period, the MOH costs and the community costs were comparable in both areas (Table 1). Around 48% of MOH expenditure was for wages. In control areas, on average 2,534 houses were inspected each month, 1,850 were sprayed, and 300 kg temephos and 3.0 L adulticides were consumed. The vertical *Aedes* control program used 27 full-time equivalent (FTE) personnel. Households spent on average 2.7 h/mo in activities related to the vector control. The figures were similar in the intervention areas: 2,307 houses inspected, 1,706 sprayed, and 283 kg temephos and 2.8 L adulticides consumed. Twenty-three FTEs were used. The average time spent by households was 2.5 h/mo.

During the implementation period, there was an absolute increase in recurrent costs in both areas because of the shortening of inspection cycles and higher vector infestation levels. The number of houses inspected per month rose to 5,987 and 4,648 in the control and intervention areas, the number sprayed to 2,743 and 1,598, and employment to 37 and 30 FTEs, respectively. In the control areas, 407 kg temephos and 4.3 L adulticides were used per month, a substantial increase from the previous period. In the intervention areas, the use of chemicals slightly diminished to 249 kg and 2.6 L, respectively. In the intervention areas, there was a shift from financial to economic cost: the share of recurrent MOH costs in the total

TABLE 1
Average annual economic costs (US\$) for *Aedes* control in intervention and control areas, Santiago de Cuba, 2000–2004

	Intervention areas			Control areas		
	Baseline 2000 (%)	Intervention 2001–2002 (%)	Follow-up 2003–2004 (%)	Baseline 2000 (%)	Intervention 2001–2002 (%)	Follow-up 2003–2004 (%)
Recurrent cost						
Total	185,985 (76.3)	214,032 (63.7)	209,933 (61.1)	202,943 (77.0)	317,496 (79.3)	333,980 (83.3)
Personnel	117,289 (48.1)	137,636 (41)	144,493 (42.1)	127,706 (48.5)	206,622 (51.6)	223,116 (55.7)
Vector control staff	90,471 (37.1)	99,946 (29.8)	112,439 (32.7)	101,188 (38.4)	156,149 (39)	195,638 (48.8)
Primary health care staff	26,818 (11.0)	37,690 (11.2)	32,059 (9.3)	26,518 (10.1)	50,472 (12.6)	27,478 (6.9)
Supplies	17,354 (7.1)	15,776 (4.7)	11,048 (3.2)	19,542 (7.4)	26,853 (6.7)	28,821 (7.2)
Training and communication	6,161 (2.5)	13,516 (4)	16,868 (4.9)	5,877 (2.2)	8,706 (2.2)	10,064 (2.5)
Operating cost	45,181 (18.5)	47,103 (14)	37,520 (10.9)	49,818 (18.9)	75,315 (18.8)	71,979 (18.0)
Capital cost	458 (0.2)	692 (0.2)	1,023 (0.3)	468 (0.2)	1,018 (0.3)	1,902 (0.5)
Community cost	57,303 (23.5)	121,168 (36.1)	132,424 (38.6)	60,075 (22.8)	81,963 (20.5)	64,973 (16.2)
Total cost	243,746 (100)	335,891 (100)	344,390 (100)	263,486 (100)	400,477 (100)	400,855 (100)

cost decreased and community costs increased from 23.5% to 36.1%. The time invested by households rose to 6.4 h/mo. In the control areas, the relative share of the different cost items remained the same.

During the follow-up period, the relative shares of the recurrent MOH costs remained, in both areas, globally at the level of the implementation period. However, salary costs for the vertical *Aedes* control program staff increased (partly because of the pay raises in 2004), whereas salary cost for PHC staff decreased because of its reduced involvement in *Aedes* control program activities (many doctors went abroad in that period to work in Cuba's international medical aid schemes). The opposite trend in the cost for supplies, including chemicals, persisted: in the intervention areas, this cost further decreased, whereas in the control areas, it further increased. The community cost remained quite stable in the intervention areas, taking into account the increase in public sector salaries (our basis for valuing unpaid community work). In the control areas, community costs decreased from 20.5% to 16.2% of the total cost.

Although economic or societal costs per inhabitant (p.i.) were comparable in both areas at baseline, they had reached, by the end of the implementation period in 2002, \$US 38.2 in the control versus \$US 30.7 in the intervention areas (Table 2).

However, the cost for the community was substantially higher in the intervention areas.

In the follow-up period, the average costs p.i in both areas was quite similar to the ones observed during the implementation period. In particular, the societal, MOH, and vertical *Aedes* control program costs p.i remained consistently higher in the control areas than in the intervention areas, whereas the community cost p.i was substantially lower in the control areas.

Taken over the 5 years of the study (2000–2004), the MOH cost p.i. remained stable in the intervention areas, whereas in control areas, it increased by ~70%. The community cost doubled in the former areas, whereas it remained fairly stable in the latter ones. The societal cost increased by 40% and 50% in intervention and control areas, respectively. This increase is mainly attributable to increasing community costs in intervention areas and to increasing costs of the vertical *Aedes* control program in control areas.

Effectiveness. No dengue transmission was detected during the study. In the implementation period, both areas showed a similar decrease from baseline in the number of *Aedes* foci (Table 3). During the follow-up period, the reductions from baseline further increased in the intervention areas, whereas in the control areas, they reverted to levels above baseline.

Cost-effectiveness. From the societal and the MOH perspectives, the community-based approach intertwined with the vertical *Aedes* control was more cost-effective during the implementation period (Table 4). It cost less and had similar effectiveness as the vertical *Aedes* control program only. During the follow-up period, the community-based approach turned out dominant: it was both more effective and less costly. The cost-effectiveness ratio of the vertical *Aedes* control program alone became negative in this period because there was an increase instead of a reduction in foci respective to baseline.

Taken over the whole period 2001–2004, the incremental cost-effectiveness ratio is negative; the community-based approach dominates the vertical *Aedes* control program both from the MOH and from the societal perspectives.

Willingness to pay for or to participate in *Aedes* control. In the intervention and the control areas, only a minority of households were willing to directly pay for *Aedes* source reduction, with the notable exception of acquiring a new

TABLE 2
Cost (US\$) for *Aedes* control per inhabitant per year in intervention and control areas, Santiago de Cuba, 2000–2004

Year	Societal cost		MOH cost		Vertical program cost		Community cost	
	Intervention	Control	Intervention	Control	Intervention	Control	Intervention	Control
2000	21.2	24.1	16.2	18.0	13.9	16.0	5.0	5.5
2001	27.6	35.2	18	26.7	14.9	22.4	9.6	8.5
2002	30.7	38.2	19.3	31.6	15.8	26.7	11.4	6.5
2001–2002	29.2	36.7	18.6	29.2	15.4	24.5	10.5	7.5
2003	29.0	35.1	18.2	29.6	14.9	26.7	10.8	5.5
2004	30.6	38.3	18.5	31.9	16.2	29.8	12.2	6.4
2003–2004	29.8	36.7	18.3	30.8	15.5	28.2	11.5	5.9

TABLE 3
Effectiveness of *Aedes* control in intervention and control areas, Santiago de Cuba, 1998–2004

	Intervention areas			Control areas			<i>P</i> value*
	House index		No. of foci	House index		No. of foci	
	Mean (SE)	Median		Mean (SE)	Median		
1998	1.67 (0.26)	1.42	482	1.61 (0.20)	1.30	501	0.5
1999	1.93 (0.33)	1.57	557	1.86 (0.28)	1.38	580	0.4
2000	2.23 (0.41)	1.23	614	2.21 (0.08)	2.08	632	0.8
2001	0.99 (0.13)	0.78	272	0.94 (0.07)	1.04	274	0.7
2002	0.56 (0.10)	0.35	155	0.55 (0.06)	0.52	165	0.75
2003	0.28 (0.03)	0.16	78	2.03 (0.09)	2.05	562	< 0.0001
2004	0.22 (0.02)	0.17	62	2.36 (0.10)	2.25	633	< 0.001
Baseline (1998–2000)							
Annual average			551			571	
Implementation (2001–2002)							
Annual average			214			220	
Difference from baseline			338			352	
Follow up (2003–2004)							
Annual average			70			598	
Difference from baseline			481			–27	
Overall intervention (2001–2004)							
Annual average			142			409	
Difference from baseline			409			163	

*Difference between control and intervention areas.

hermetic water storage tank (Table 5). However, the amounts that households were willing to invest in a tank were small. On the other hand, households in both areas were quite—and equally—willing to devote time to cooperate with vector control workers during house inspections. However, willingness to spend time to eliminate oneself environmental risks and to attend community meetings was significantly higher in the intervention than in the control areas. In both areas, the household's self-declared willingness to spend time on *Aedes* control activities was somewhat higher than the actual time spent. Notwithstanding, the actual time spent by households was markedly and significantly higher in the intervention areas.

DISCUSSION

This study indicates that, in Santiago de Cuba, a community-based approach intertwined with a routine vertical *Aedes* control program is more efficient and more effective than vertical control alone, even after the withdrawal of the external support for launching the approach. Although our study was not a randomized community trial, intervention and control areas were comparable at baseline, and there were no differential external influences during the implementation and follow-up

period. It is therefore fair to assume that differences in reductions in the number of foci are attributable to differences in effectiveness.

Also very encouraging was the marked and sustained reduction in the use of insecticides and larvicides in the intervention areas. This is clearly a positive environmental outcome that also entails economic advantages, in particular when the chemicals are purchased abroad in hard currency.

As we pointed out previously, the effectiveness of vector control interventions is difficult to determine in non-endemic settings such as Cuba²⁰ because one can not measure changes in dengue incidence rates. Entomologic indices are surrogate markers for epidemic risk, and their functional relationship with the occurrence of dengue outbreaks is not well known.^{21,22} Moreover, in the Cuban context, entomologic indices are very low, and the cost per unit reduction is difficult to interpret. Therefore, we used “average annual difference in foci” as the effect measure. It was derived using routine data that, given the vertical *Aedes* control program's systematic supervision and quality control, should be reliable.²³ Furthermore, underestimation of larval prevalence, if any, is expected to be non-differential.

Whereas in the intervention areas, the number of foci was further reduced in 2003–2004, there was a significant increase

TABLE 4
Cost-effectiveness ratios and incremental cost-effectiveness ratios for *Aedes* control in intervention and control areas, Santiago de Cuba, 2001–2004

Perspective	Intervention areas			Control areas			Incremental cost-effectiveness
	Average annual cost	Average annual effectiveness	Cost-effectiveness ratio	Average annual cost	Average annual effectiveness	Cost-effectiveness ratio	
MOH							
2001–2002	214,723	338	636.2	318,514	352	906.2	7,414
2003–2004	211,966	481	440.7	335,882	–27	–12,674.8	–244
2001–2004	213,344	409	521.3	327,198	163	2,013.5	–461
Society							
2001–2002	335,892	338	995.2	400,477	352	1,139.3	4,613
2003–2004	344,390	481	716.0	400,855	–27	–15,126.6	–111
2001–2004	340,141	409	831.1	400,666	163	2,465.6	–245

TABLE 5
Household willingness to pay or to invest time in activities related to the *Ae. aegypti* control and observed practices, Santiago de Cuba, 2004

	Willingness				Observed practice			
	Percent of respondents willing to pay/invest time (N = 200)		Price† (% in category) or average time (SD)		Average (SD)		P value*	
	Intervention areas	Control areas	Intervention areas	Control areas	Intervention areas	Control areas	Intervention areas	Control areas
Buy a new hermetic 150-L plastic water storage tank	65.0%	60.0%	Not willing (35%) 50–100 (60.0%) 101–150 (3.0%) 151–200 (2.0%) 201–250 (0%)	Not willing (40%) 50–100 (53.0%) 101–150 (4.0%) 151–200 (2.0%) 201–250 (1.0%)	Government sells the tanks at 250 CUP‡	—	> 0.05	—
Pay a person for cleaning the yard (once)	21.0%	18.0%	Not willing (79%) 10–15 (8.5%) 16–20 (5.0%) 21–25 (7.5%)	Not willing (82%) 10–15 (9.0%) 16–20 (5.0%) 21–25 (4.0%)	The local average market rate is 20 CUP	—	> 0.05	—
Pay for eliminating garbage accumulated in public areas (once)	25.0%	24.1%	13.3 (4.31)	15 (3.8)	Cost assumed by the government	—	> 0.05	—
Cooperate with vector control workers (minutes per inspection)	99.5%	95.0%	20.5 (10.1)	20.0 (7.3)	18.0 (7.3)	17.3 (6.9)	> 0.05	> 0.05
Eliminate environmental risks in the house yard (h/mo)	99.0%	98.0%	32.0 (13.8)	31.0 (12.7)	30.5 (15.5)	30.0 (13.8)	> 0.05	> 0.05
Eliminate environmental risks in public areas (h/mo)	95.0%	22.4%	4.10 (2.50)	1.20 (0.47)	3.45 (2.30)	1.0 (0.30)	< 0.05	< 0.05
Participate in community meetings related to <i>Aedes</i> control (h/mo)	95.0%	55.8%	2.20 (0.51)	1.00 (0.45)	2.00 (1.10)	0.42 (0.20)	< 0.05	< 0.05
	98.0%	19.4%	1.0 (0.45)	0.28 (0.20)	0.45 (0.32)	0.20 (0.10)	< 0.05	< 0.05

* Difference between control and intervention areas.

† National pesos (CUP).

in the control areas. In Santiago de Cuba, environmental risks favor *Aedes* proliferation in public areas and in the peri-domestic environment. The vertical *Aedes* control program, which has resource constraints during non-epidemic periods, seems unable to eliminate those risks, and it seems to be a good investment to complement its actions with a community-based participatory approach to *Aedes* control. Notwithstanding, our analysis showed that community participation does not come as a free ride: the costs for the community increases. Additionally, reductions in the number of foci are costly when the levels of infestation are low.

We estimated that the 2004 societal cost of *Aedes* control in Santiago amounts to \$US30.6 and \$US38.3 per inhabitant for the intervention and control areas, respectively; the vertical *Aedes* control program cost is \$US16.2 and \$US29.8, respectively. There are very few published studies that have cost *Aedes* control to compare these figures with. Armien and others²⁴ estimated that vector control during the 2005 dengue epidemic in Panama cost US\$1.56 per inhabitant. In Cambodia,²⁵ larviciding twice a year with temephos—in accessible water storage containers of 100 L or more and attaining 23% coverage—cost US\$0.20 per inhabitant per year. However, a wide array of differences with the above interventions, in terms of developed activities, treatment frequencies, and attained coverage, as well as substantial differences in the epidemiologic backgrounds, preclude direct comparisons with our results. Thus, it is also difficult to extrapolate the cost-effectiveness figures, in particular to endemic countries with high *Aedes* infestation. Notwithstanding, our results clearly indicate that substantial investments are needed to achieve and maintain successful vector control and that, certainly at low infestation levels, the cost to do better is high. Furthermore, the degree and type of community participation we observed is probably highly dependent on the specific socio-cultural context of Cuba. For example, although households were willing to devote time for vector control, many of them were not willing to spend money for environmental management to maximize the utility (i.e., the subjective benefit) of cash expenditure for other priorities. These contextual differences make it hard to answer questions on the reproducibility of our community approach in different settings.

Nonetheless, our central finding, the higher efficiency of a community-based approach intertwined with a vertical *Aedes* control program, is generalizable if key elements are recognized and translated in a relevant way to other contexts. Community participation in environmental management activities was set up to favor capacity building and empowerment of vector control workers and community alike and focused on increasing awareness of health benefits and on building new alliances to achieve results.¹⁴ The community's disposition to participate in control activities can be seen as an increased demand for health care and willingness to contribute to preventive health measures within one's own time and financial limits. Jensen²⁶ showed the importance for sustainability of beneficiaries' willingness and ability to pay for health services. Wiesemann and others²⁷ showed that participants of educational courses are willing to pay for preventive health measures and this was without correlation with income. Finally, Bossert²⁸ and Shediak-Rizkallah and Bone²⁹ have identified capacity building as crucial for the sustainability of health programs. Therefore, we believe that vertical *Aedes* control programs in other countries can effectively tap additional "community resources" to make their actions more

effective and economically sustainable, on the condition that they invest in raising awareness, building capacity, and in partnerships between the community and the vertical *Aedes* control program.

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