

Gravitraps for Management of Dengue Clusters in Singapore

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Abstract. Although Singapore has an intensive dengue control program, dengue remains endemic with regular outbreaks. We report development and use of a novel adult oviposition trap, the Gravitraps, in managing dengue cluster areas. The Gravitraps is a simple, hay infusion-filled cylindrical trap with a sticky inner surface to serve as an oviposition site for gravid female *Aedes* mosquitoes. Wire gauze fitted above the water level minimizes the risk of it being an unwanted breeding habitat. The Gravitraps was deployed in 11 dengue cluster areas throughout Singapore. *Aedes aegypti* was the predominant mosquito caught in the trap and some (5.73%) were found to be positive for dengue virus.

Most (85%) of the population in Singapore dwells in high-rise apartments.¹ This population faces regular outbreaks of dengue because of its high level of urbanization, high population density, low herd immunity, intense travel pattern, presence of *Aedes* vectors² and possibly natural adaptation/selection of dengue viruses (DENVs) under the pressure of small populations of *Aedes* mosquitoes.³ Source reduction and environmental management are the hallmarks of the nation's vector control strategy, which decreased House Index (HI) from more than 50% in the 1960s and 1970s to 0.3% in the 2000s. Dengue control programs are challenged by the lack of cost effective tools that could trap adult *Aedes* mosquitoes and provide a reasonable population estimate of *Aedes* mosquitoes in the environment. This report describes development by the Environmental Health Institute of the Gravitraps, which is designed to lure and trap gravid female *Aedes* with a sticky lining. It exploits the skip-oviposition behavior of female *Aedes aegypti*, who distributes her eggs in multiple containers during each gonotrophic cycle, a behavior that may increase offspring survival.^{4,5}

The Gravitraps is simple and economical to fabricate and is composed of a black container containing 10% hay infusion and an inner shorter cylinder lined with adhesive glue (URV32-Catchmaster; AP&G, Inc., Brooklyn, NY) to trap gravid females searching for oviposition sites (Figure 1). To prevent emergence of adults, in the event that eggs are laid before gravid females are trapped, the smaller inner cylinder is fitted with a wire netted base, which sits above two draining holes punctured through the outer container, 7 cm from the bottom of container.

A field trial with 303 Gravitraps was conducted in nine architecturally similar apartment blocks of 12–13 stories within an area of 0.07 km² to assess the effectiveness of Gravitraps. Surveillance has shown that *Ae. aegypti* was the predominant mosquito in the area, which is flanked by roads with moderately heavy traffic. Three Gravitraps were placed approximately 25–30 meters apart on each floor of each block, starting at the second level. Six ovitraps were also set in each block (two per 4th, 7th, and 10th/11th floors) as monitoring tools. All Gravitraps and ovitraps were maintained and checked weekly for 16 weeks.

The total number of eggs collected from the ovitraps per week varied from 281 (week 12) to 2,920 (week 1) for the duration of the study. The Gravitraps trapped 517 adult *Ae. aegypti*, 86 *Ae. albopictus*, 17 *Aedes* species (which could not be speciated because of damage), and 7 *Culex* species. There was a significant correlation between the adult mosquitoes caught in Gravitraps and the number of eggs deposited into the ovitraps each week (Figure 2) (Pearson correlation $r = 0.607$, $P < 0.05$). Overall, the trap was found to be effective in catching adult *Ae. aegypti*, and was easy to deploy, with little risk of becoming a breeding habitat. The number of mosquitoes caught in the Gravitraps was found to be unequally distributed among different floors in the apartment blocks (Figure 3) ($\chi^2 = 188.5$, degrees of freedom = 11, $P < 0.001$), with a higher percentage (64.91%) of mosquitoes trapped on floors 2–6, and floors 7–13 had a lower percentage (35.09%) (Figure 3). The current findings are consistent with those of previous studies that had found that *Ae. aegypti* prefer to breed near ground level.^{6–8}

A total of 551 Gravitraps were set up in 11 dengue cluster areas (June–November 2010) to determine their effectiveness in collecting dengue-infected mosquitoes and to complement source reduction efforts in controlling transmission. A cluster is defined as two or more cases of dengue that reside within 150 meters of each other and have disease onset dates that are within 14 days of each other (Table 1 and Figure 4). All Gravitraps were set up in corners where mosquitoes were likely to be resting or breeding (i.e. cool, shaded areas or around potted plants), along the common corridors of the apartments or backyards of landed houses. The Gravitraps were placed on the ground level, 2nd and 6th floors, which have long stretches of corridors that span across the block, and 4–6 traps were placed in each apartment block with reported dengue cases. The Gravitraps were checked and hay infusion water was replaced every 3–4 days. Abdomens of trapped *Aedes* mosquitoes were pooled into groups of five and screened for DENV by using the Dengue NS1 Ag Strip (Bio-Rad, Marnes-la-Coquette, France). Individual mosquitoes from NS1-positive pools were tested for DENV by using a real-time polymerase chain reaction.⁹

Aedes mosquitoes were caught in all but one of the clusters (Table 1). Dengue virus-infected *Ae. aegypti* were detected in half ($n = 6$) of the clusters (Figure 4). Gravitraps set near or before the peak of dengue cluster trapped at least one DENV-infected *Ae. aegypti* in each cluster area. Conversely, placing of Gravitraps towards the end of the cluster usually failed to trap any DENV-infected *Ae. Aegypti*, as seen in the

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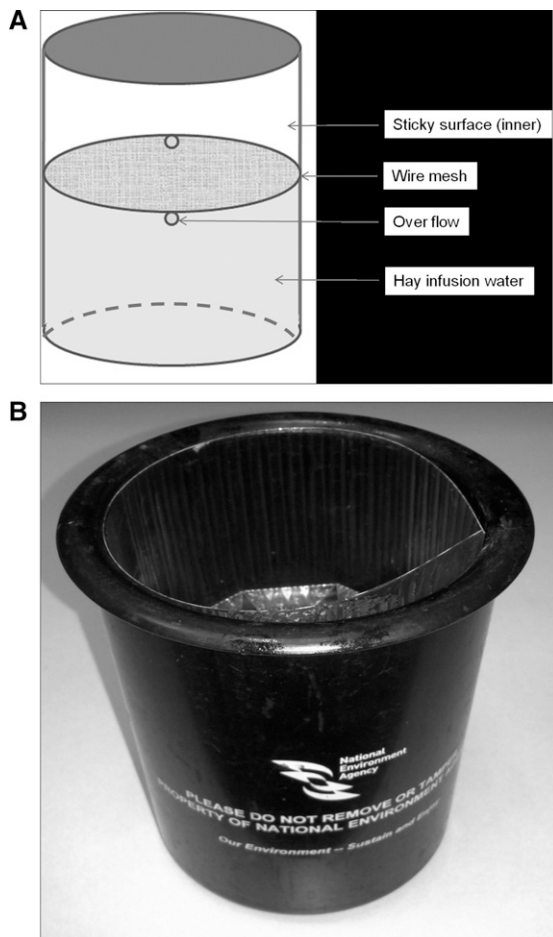


FIGURE 1. Schematic design (A) and picture (B) of Environmental Health Institute, Singapore, sticky Gravitraps.

Clementi West Ave 2, Lorong M Telok Kurau, Holland Hill, and Serangoon Ave 4 clusters. All clusters, except Telok Blangah and Serangoon Ave 2, closed within five weeks of the Gravitraps deployment. A total of 382 mosquitoes were trapped and *Ae. aegypti* was the predominant species (73.3%), and *Ae. albopictus* comprised 18.6%. Only three *Culex quinquefasciatus* mosquitoes were caught. The rest were damaged *Aedes* specimens that could not be speciated. Among trapped *Ae. Aegypti*, 15 were infected with DENV, and positivity rates ranged from 2.8 to 13.6% for each location (Table 1). No infected *Ae. albopictus* was found, confirming the primary role of *Ae. aegypti* in dengue transmission in Singapore. Real-time reverse transcription-polymerase chain reaction results for the mosquitoes also concurred with the dengue serotype in infected patients from the same cluster (Table 1).

In the Bishan St 24 and the Serangoon Ave 2 clusters, DENV-positive mosquitoes were detected beyond the period of reported transmission, suggesting that active transmission could still be ongoing despite no additional reporting of cases. This result highlights the need for continued vigilant surveillance of an area even after transmission has apparently ceased. Because of the complex interplay of multiple factors in dengue transmission and the variability in ongoing cluster control measures, it is unlikely that we can definitively demonstrate the contribution of the Gravitraps in the intervention of any dengue transmission. Nevertheless, because female *Ae. aegypti* are known to take multiple blood meals during each gonotrophic cycle,¹⁰ removal of a single infected mosquito could result in the prevention of at least 3–5 persons from becoming infected with dengue, and the avoidance of subsequent generation of cases. Moreover, because one *Aedes* female mosquito could lay approximately 80–100 eggs after a single blood meal,¹¹ every female mosquito trapped could also prevent emergence of tens or hundreds of progenies.

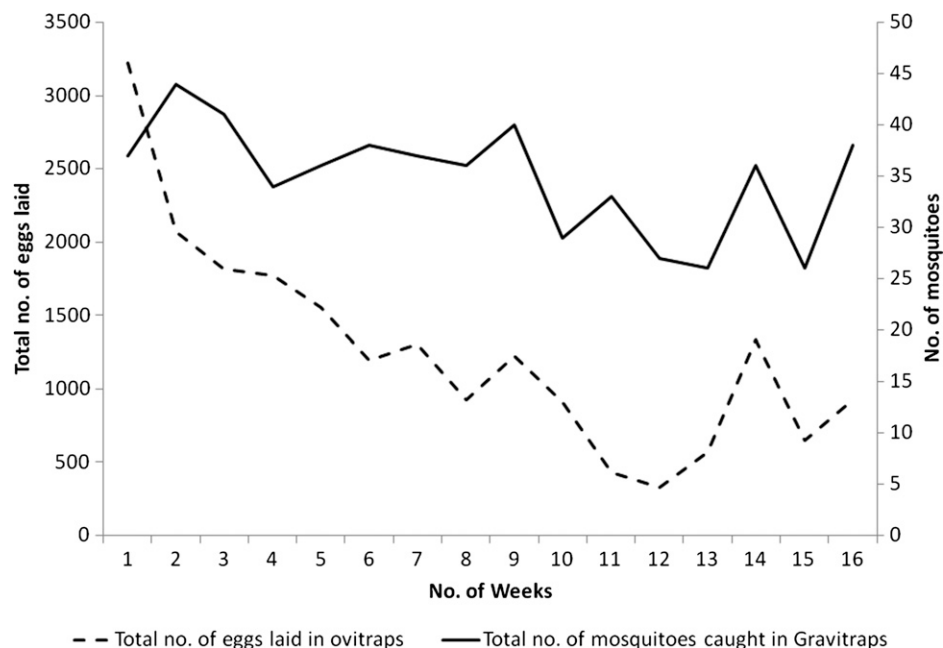


FIGURE 2. Total number of eggs laid in the ovitraps (red line) compared with the total number of mosquitoes trapped (blue line) across 16 weeks in first trial, Singapore.

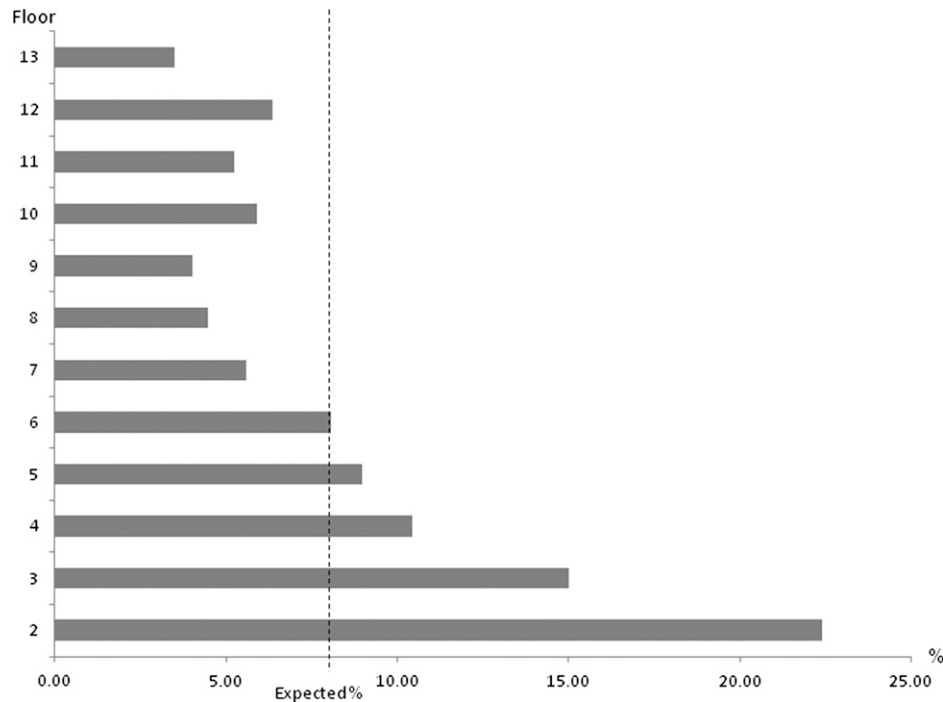


FIGURE 3. Distribution of *Aedes* mosquitoes trapped in Gravitraps between different floors during the first trial, Singapore. Values are the percentage of the total number of mosquitoes trapped. The dotted line shows the expected percentage of mosquitoes trapped on each floor (8.33%) if mosquito distribution was equal.

Globally, current transmission control relies on insecticide sprays, which are plagued by many issues: development of insecticide resistance, toxicity to non-target insects, and limited accessibility of homes to target indoor dwelling *Ae. aegypti*. The Gravitraps is an attractive, environmentally friendly, and convenient tool to lure and remove *Aedes* mosquitoes. The challenge in its use for control of dengue transmission lies in the timing of deployment. Early deployment would result in resources being thinly spread, and late deployment could render it ineffective. The chance and rate of trapping infected *Aedes* mosquitoes is

influenced by factors that include the extent and duration of transmission (reflected by number of dengue cases), location of the Gravitraps, time of deployment (Figure 3), competition from cryptic oviposition sites in the environment, and success of community participation in source reduction.

Nevertheless, a large number of the Gravitraps (more than 40 or at least five traps in each apartment block) is needed for trapping of any infected adult *Aedes* mosquito. The Gravitraps may also provide a measure of the *Aedes* population, and the infective status of trapped *Aedes* mosquitoes could assist in

TABLE 1
Summary of 11 dengue cluster areas where the Gravitraps were deployed and the number of mosquitoes trapped, Singapore*

Cluster area	No. dengue cases (dengue virus serotype of patients)	No. traps deployed	No. weeks deployed	No. mosquitoes trapped					No. mosquitoes positive (dengue virus serotype)	% <i>Ae. aegypti</i> positive
				<i>Aedes aegypti</i>	<i>Ae. albopictus</i>	<i>Aedes</i> sp.	<i>Culex</i> sp.	Total		
Central Singapore										
Cairnhill	106 (DENV2)	40	9	9	25	0	0	34	1 (DENV2)	11.1
Telok Blangah	149 (DENV2)	104	7.5	44	14	10	2	70	6 (DENV2)	13.6
Eastern Singapore										
Lorong M Telok Kurau	36 (Unknown)	10	3.5	0	0	0	0	0	0	
Livia Pasir Ris	57 (Unknown)	14	3	7	0	0	0	7	0	
Pasir Ris St 52	52 (Unknown)	45	4	10	3	0	0	13	1 (DENV2)	10.0
Western Singapore										
Clementi West Ave 2	46 (Unknown)	36	7	13	3	5	0	21	0	
Holland Hill	40 (Unknown)	20	4.5	2	1	0	0	3	0	
Northeastern Singapore										
Serangoon North Ave 4	36 (Unknown)	44	6	20	8	2	1	31	0	
Serangoon Ave 2	71 (DENV1)	85	10	97	14	3	0	134	4 (DENV1)	4.1
Ang Mo Kio Ave 8	17 (DENV2)	58	5.5	36	1	1	0	38	1 (DENV2)	2.8
Bishan St 24	49 (DENV2)	41	6.5	24	1	4	0	29	2 (DENV2)	8.3

*No. of traps deployed in Telok Blangah increased from 57 to 104 over 7.5 weeks. No. of traps deployed in Cairnhill increased from 25 to 40 over 9 weeks. DENV = dengue virus.

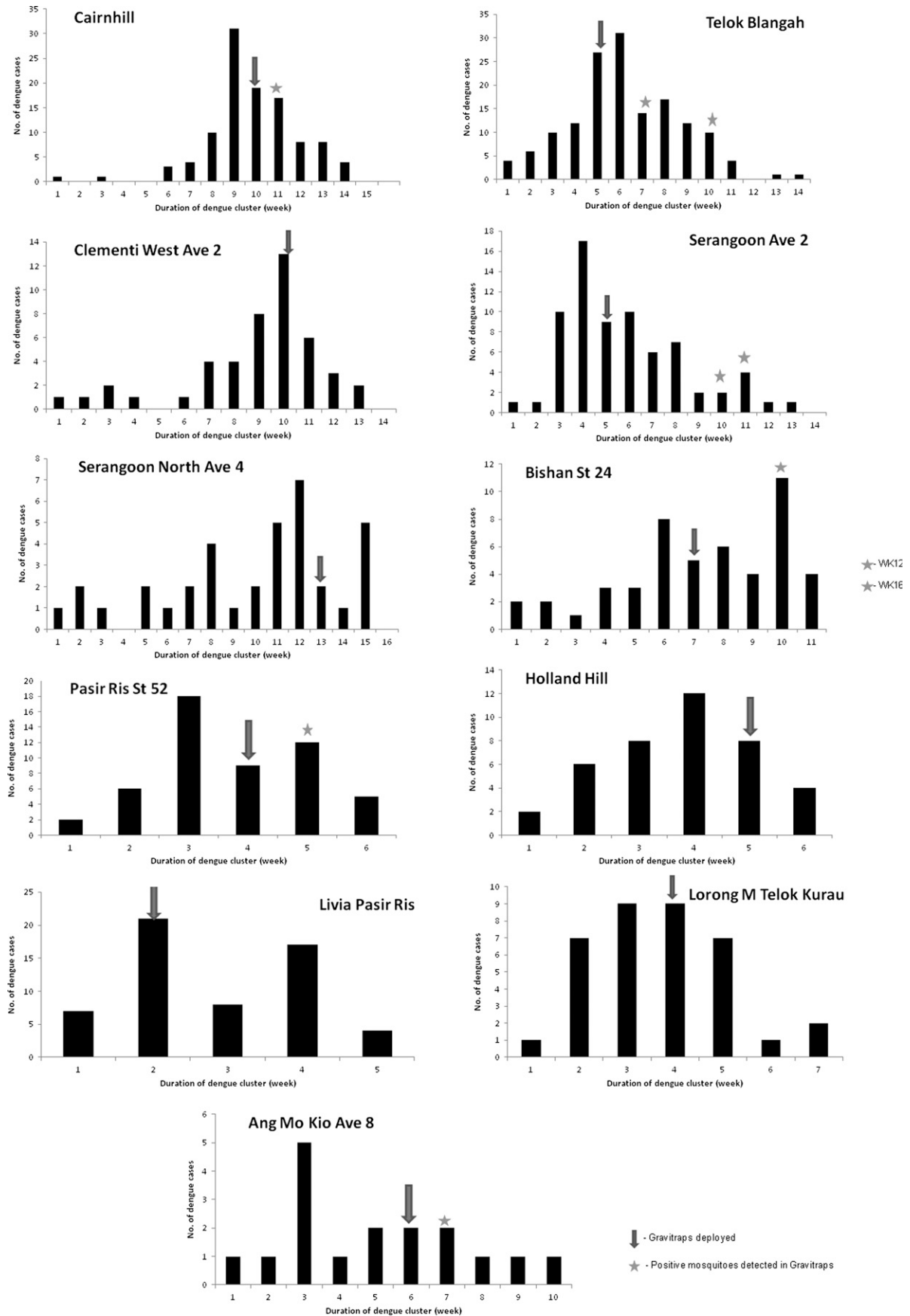


FIGURE 4. Summary of the epidemiologic profile of 11 dengue cluster areas in Singapore in 2010. Each profile includes the duration of deployment of the Gravitraps and the detection of dengue virus-positive mosquitoes.

situational risk assessment and operational decision making in controlling outbreaks. In Singapore, these traps have served as an evaluation tool to ascertain effectiveness of ground mosquito control measures.

Although there have been a number of sticky traps developed and reported, such as the MosquiTrap™¹² and the CDC gravid trap,¹³ the hallmark of the Gravitrap is its simplicity and a physical barrier to prevent emergence of adult mosquitoes in case eggs are laid before trapping of gravid females. The simplicity and fail-safe design are particularly important to enable it to be deployed by the community, an approach consistent with Singapore's advocacy for community participation. Currently, a chemical lure is under development to replace the hay infusion water to enable its wide and regular use by the community to prevent dengue transmission.

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