

ROOF GUTTERS: A KEY CONTAINER FOR *Aedes aegypti* AND *Ochlerotatus notoscriptus* (DIPTERA: CULICIDAE) IN AUSTRALIA

BRIAN L. MONTGOMERY AND SCOTT A. RITCHIE
Tropical Public Health Unit Network, Cairns, Queensland, Australia

Abstract. The contribution of roof gutters to *Aedes aegypti* (L.) and *Ochlerotatus notoscriptus* (Skuse) pupal populations was quantified for the first time in Cairns, Australia. Concurrent yard and roof surveys yielded an estimated 6,934 mosquito pupae, comprising four species. Roof gutters were an uncommon but productive source of *Ae. aegypti* in both wet season ($n = 11$) and dry season ($n = 2$) surveys, producing 52.6% and 39.5% of the respective populations. First story gutters accounted for 92.3% of the positive gutters. Therefore, treatment of roof gutters is a critical element in *Ae. aegypti* control campaigns during dengue outbreaks. In wet season yards, the largest standing crops of *Ae. aegypti* occurred in garden accoutrements, discarded household items, and rubbish (36.4%, 28.0%, and 20.6%, respectively). In dry season yards, rubbish produced 79.6% of the *Ae. aegypti* pupae. The number of *Ae. aegypti* pupae/person was 2.36 and 0.59 for the wet and dry season surveys, respectively.

INTRODUCTION

Outbreaks of dengue in Australia are restricted by the distribution of the vector *Aedes aegypti* to Queensland. Dengue control campaigns traditionally target water-bearing containers including artificial containers, e.g., discarded tires, plant pot bases, rainwater tanks and domestic rubbish;¹ natural containers, e.g., fallen palm fronds and bromeliad leaf axils;¹ and subterranean sites, e.g., mine shafts, service pits, and wells.^{2,3} Containers that produce disproportionate numbers of *Ae. aegypti* are termed key containers.⁴ In areas of northern Queensland without piped water, rainwater tanks are a key container,⁴ while in Fiji, tires and drums are key containers.⁵ Because a single key container may contain several hundred larvae, they must be located for adequate control of *Ae. aegypti*.

Some key containers for *Ae. aegypti* are covert. In northern Queensland, subterranean habitats (e.g., wells, service pits, and septic tanks) represented only 15% of the breeding sites but accounted for 85% of the standing crop of third to fourth instar *Ae. aegypti*.⁶ Covert elevated sites, such as rainwater tanks, were a key container in the Torres Strait during a dengue-2 outbreak.⁷ Roof gutters are presumed breeding sites for *Ae. aegypti*, although evidence is largely anecdotal or obscured within a “building fixture” category.^{1,8,9} Laird made no mention of roof guttering in his review of mosquito larval habitats.¹⁰ Roof gutters commonly contained *Ae. aegypti* in Surinam, but production was not quantified.¹¹

To quantify the relative production of *Ae. aegypti* in roof gutters, we conducted pupal surveys¹² of surface containers and roof gutters in Cairns, Australia during the wet and dry seasons.

MATERIALS AND METHODS

The climate of Cairns (16°55'S, 145°46'E; population = 102,000; area = 437 km²) is tropical; the wet months (November–April) are hot and humid with frequent heavy rainfall, while the dry months (May–October) are cooler and less humid with minimal rain. Residential areas with a history of dengue were sampled in the wet and dry seasons. Most premises were historic (50–100 years old) Queensland-style wooden houses, with large verandas, and often elevated with unscreened windows to enhance ventilation. The dry season

survey (210 houses) in the suburbs of Machans Beach, North Cairns, and Parramatta Park was conducted between May 12 and 21, 1999; weather during the period featured 0.6 mm of rain, a daily mean temperature of 24.6°C, 9.3 hours of sunshine, and total evaporation of 65 mm. Corresponding weather conditions for the preceding four weeks (April 14–May 11, 1999) were 113.6 mm, 23.4°C, 5.4 hours, and 137 mm, respectively. The wet season survey (200 houses; March 21–April 19, 2000) was conducted in Edge Hill, North Cairns, Parramatta Park, Stratford, and Westcourt. The weather during this survey featured 363.6 mm of rain, a daily mean temperature of 25.7°C, 6.8 hours of sunshine, and total evaporation of 148 mm. Corresponding weather conditions for the preceding four weeks (February 22–March 20, 2000) were 815.2 mm, 25.7°C, 4.4 hours, and 115 mm, respectively.

Yards and roof gutters were surveyed concurrently. Within a suburb, the initial house was selected randomly; subsequent houses within 500 meters were systematically visited and sampled if permission was granted. Yards were visually inspected for containers that could hold water. Each mosquito-breeding container was categorized,¹ exhaustively sampled, and pupae were counted to assess productivity.¹² Representative samples of pupae were collected and emerged adults were identified in the laboratory and used to estimate the number of pupae for each species.

All selected roof gutters were visually inspected. The length of guttering flooded and shaded (from midday sun), gutter height, and any distinctive characteristics were recorded. The wet season survey also included measurements of the gutter length and an assessment of the Premise Condition Index (PCI).¹³ Gutters with small amounts of water were exhaustively sampled using a turkey baster. For deeply flooded guttering, a linear meter was randomly selected in any flooded gutter and small sandbags placed at either end to contain pupae. Leaf litter was removed by hand before sweeping flooded areas with a small net (Second Nature Soft-Net;® Tetra Sales, Morris Plains, NJ). Pre-testing determined that four sweeps of a 10 × 12.5 cm net through one linear meter of gutter recaptured 71% of the *Ae. aegypti* pupae ($n = 10$, mean ± SEM = 7.1 ± 0.53). The number of pupae/gutter was then estimated by extrapolation incorporating a sampling efficiency of 71% and the proportion of flooded guttering that was sampled.

The density of *Ae. aegypti* pupae per person¹² was deter-

mined by combining the results of yard and roof gutter surveys. The number of people per house was estimated from relevant Cairns inner city statistical local area boundaries and Australian Bureau of Statistics 1996 Census of Population and Housing data.

RESULTS

Species composition. An estimated 6,934 mosquito pupae were found during the wet and dry season surveys, with 88.7% collected in the wet season. *Culex* species, *Ae. aegypti*, *Ochlerotatus notoscriptus*, and *Oc. palmarum* Edwards comprised 56.1%, 24.4%, 18.8%, and 0.5% of the total pupal population, respectively. Dead pupae (0.2%) were not speciated. *Culex* species pupae dominated the wet season yard survey (62.3%) due to an estimated 3,375 *Cx. quinquefasciatus* Say (estimated from a 10-liter subsample) in a 675-liter ornamental pond. Other *Culex* pupae consisted of *Cx. annulirostris* Skuse and *Cx. halifaxii* Theobald. *Culex* species were uncommon (7.3%) in the dry season survey.

Aedes aegypti and *Oc. notoscriptus* were similarly prevalent during the dry season survey (49.5% and 50.5% of aedine pupae, respectively). *Aedes aegypti* was more abundant during the wet season survey, followed by *Oc. notoscriptus* and *Oc. palmarum* (57.8%, 40.7%, and 1.5% of aedine pupae, respectively).

Roof gutter surveys. A total of 212 pupae, giving an estimated population of 1,472 pupae, were collected from 13 roof gutters at 11 premises (Table 1). Therefore, roof gutters with pupae were uncommon (2.7%) but productive sites. Pupae were either *Ae. aegypti* or *Oc. notoscriptus* (57.3% and 42.7%, respectively), with 49.8% and 48.2% of the respective standing crop (roof gutter plus yard survey) originating from roof gutters. No *Cx. quinquefasciatus* were collected from roof gutters.

In the wet season, 527 gutters encompassing a length of 3,398 meters were inspected. Of these, 77 (14.6%) were flooded, with a total submerged length of 464.5 meters. Mosquito pupae were found in 11 (13.7%) flooded gutters. These flooded gutters were the primary source of *Ae. aegypti* and *Oc. notoscriptus* pupae (52.6% and 66.8%, respectively) in the wet season. In the dry season, only two roof gutters contained mosquito pupae but accounted for 39.5% of the *Ae. aegypti* pupae.

Premises with Queenslander-style houses produced half (54.5%) of the positive roof gutters; 36.4% of these were on

car sheds. Most positive gutters (92.3%) were ground floor (elevation < 3 meters). Shade was not an exclusive indicator for infested gutters; 36.4% of the positive gutters were not shaded. Interestingly, well-maintained properties were as likely to produce pupae in roof gutters as poorly maintained properties; eight of 13 premises with positive gutters had a PCI \leq 5.

Yard surveys. Seasonal differences in the magnitude and species composition were noted in the yard survey (Table 1). In the wet season survey, 634 *Ae. aegypti* pupae were collected from 70 containers within seven categories. Garden accoutrements (plant pot bases, birdbaths) were the most abundant ($n = 28$) positive containers, followed by rubbish (12), discarded household items (11), and domestic-commercial usage containers (9). Garden accoutrements, discarded household items, and rubbish contained the largest proportion of *Ae. aegypti* pupae (36.4%, 28.1%, and 20.6%, respectively). However, the highest mean number of *Ae. aegypti* pupae per container occurred in discarded household items, followed by rubbish, garden accoutrements, and domestic-commercial usage containers (16.2, 10.9, 8.2, and 7.0, respectively). These four categories generated 95% of the *Ae. aegypti* pupae in yards. A total of 312 *Oc. notoscriptus* pupae was collected in 25 containers, with garden accoutrements, natural breeding sites, and domestic-commercial usage containers accounting for most positive containers. These three categories generated 98.2% of the pupae, with garden accoutrements the most productive (mean = 20.5 pupae).

In the dry season, the productivity of *Ae. aegypti* decreased while the *Oc. notoscriptus* pupal count was relatively unchanged (Table 1). Rubbish items (two polystyrene boxes and two tires) produced 79.6% of the *Ae. aegypti* pupae, 97.1% from the two boxes. The other container categories produced less than five pupae per positive container. The mean number of *Oc. notoscriptus* pupae per container was highest in rubbish (71.6), followed by domestic-commercial usage containers (20.7), and discarded household items (11.0). These three categories generated 99.5% of the pupae.

Pupal indices. *Aedes aegypti* pupal indices were highest in the wet season (Table 1), ranging from 2.36 to 0.59 for the wet and dry season surveys, respectively.

DISCUSSION

This is the first quantification of mosquito production by roof guttering in Australia. Roof gutters in Cairns were un-

TABLE 1
Pupal surveys of *Aedes aegypti* and *Ochlerotatus notoscriptus* in roof gutters and yards in Cairns, Australia

Survey	Premises (hectares) surveyed	Survey sites	Positive containers (no./hectare)	<i>Ae. aegypti</i>		<i>Oc. notoscriptus</i>
				Positive containers; no. of pupae	Pupal index (no./hectare; no./person)	Positive containers; no. of pupae
Dry season (May 12–21, 1999)	210 (26.3 hectares)	Gutters	2 (0.08)	2; 141*	5.4; 0.23	0; 0*
		Yard	36 (1.39)	19; 216	8.2; 0.36	13; 364
		Combined	38 (1.44)	21; 357	13.6; 0.59	13; 364
Wet season (March 21–April 14, 2000)	200 (26.8 hectares)	Gutters	11 (0.41)	10; 703*	26.2; 1.24	6; 628
		Yard	97 (3.62)	70; 634	23.7; 1.12	25; 312
		Combined	108 (4.03)	80; 1337	49.9; 2.36	31; 940

* Number of pupae in a flooded gutter was estimated from a randomly-selected 1-m length of flooded gutter and corrected for a sampling efficiency of 71%.

common but productive sites for *Ae. aegypti* in both wet and dry season surveys, producing an estimated 50.9% and 39.3% of the pupae, respectively. While only four gutters contained *Oc. notoscriptus* pupae, they produced an estimated 628 pupae, 66.8% of the standing crop in the wet season. However, because the entire flooded gutter was not sampled, estimates of mosquito pupae may be in error. Nonetheless, the large number of pupae ($n = 246$ corrected for 71% sampling efficiency) collected from only a sample of flooded gutters indicates that gutters are indeed a key container for *Ae. aegypti* and *Oc. notoscriptus* in Cairns. The disproportionate production of mosquitoes by guttering may be due to the abundance of nutrients, in the form of fallen leaves and detritus,¹⁴ that accumulate in blocked guttering. Traditional source reduction operations often exclude guttering. Failure to treat these key containers would compromise the efficacy of dengue control operations. Furthermore, the discovery of pupae of *Oc. notoscriptus*, a vector of Ross River virus,¹⁵ in roof gutters would have implications for control of Ross River virus.

Prerequisites for identifying mosquito-breeding roof gutters are elusive. The most consistent indicator was first story (height < 3 meters) guttering. Guttering on car sheds and modern houses tend to have less fall (gradient) and thus are easily blocked by debris. Thus, operational efficacy may be improved by restricting treatment with S-methoprene to low-set roof gutters (< 3 meters) since high-set roof gutters rarely produced *Ae. aegypti*. Surprisingly, shade was not a consistent indicator of positive gutters, perhaps due to prolonged wet, cloudy weather during the wet season survey that maintained flooded gutters. The PCI was also not indicative of positive guttering.

The potential productivity of roof gutters supports the Queensland Health policy of treating roof gutters. The failure to do so may increase their productivity; roof guttering became the dominant *Ae. aegypti* habitat in areas of Surinam where eradication campaigns had only targeted surface containers.¹¹

Wet and dry season surveys indicate that *Ae. aegypti* pupae were common in inner city suburban yards in Cairns. The major difference between surveys was the greater productivity in the wet season. The *Ae. aegypti* pupal population almost tripled between the dry and wet season surveys (216 and 634, respectively). Containers, particularly garden accoutrements and domestic-commercial usage containers, with *Ae. aegypti* pupae were more abundant and produced larger populations in the wet season survey. The notable exception was dry season rubbish that produced the third highest population and highest mean number of *Ae. aegypti* pupae in either survey. In contrast, rubbish items and natural breeding site populations were relatively consistent between surveys.

The combined wet survey pupae/person index of 2.36 is well above the theoretical threshold of 1.42 for dengue transmission in Cairns (based on a mean temperature of 26°C; naive immune status).¹⁶ However, the dry season value of 0.59 is less than the 2.92 pupae/person transmission threshold for dry season conditions (mean temperature = 23.4°C). The pupal populations in Cairns, while sufficient for dengue transmission, are generally less than those reported for other tropical areas.¹⁷

Acknowledgments: We are indebted to the residents of Cairns who kindly permitted inspections of yards and roof gutters. We also thank Colin Stace for inspecting roof guttering, Alistair Hart, Sharron Long, and Ian Walsh for assistance in yard surveys, and Fiona Tulip (Tropical Public Health Unit, Cairns) for census housing figures.

Financial support: This study was funded by a grant from Queensland Health.

Authors' address: Brian Montgomery and Scott A. Ritchie, Tropical Public Health Unit Network, PO Box 1103, Cairns, Queensland, 4870, Australia.

Reprint requests: Brian Montgomery, Tropical Public Health Unit Network, PO Box 1103, Cairns, Queensland, 4870, Australia. E-mail: brian_montgomery@health.qld.gov.au

REFERENCES

1. Barker-Hudson P, Jones R, Kay BH, 1988. Categorization of domestic breeding habitats of *Aedes aegypti* (Diptera: Culicidae) in northern Queensland, Australia. *J Med Entomol* 25: 178–182.
2. Russell BM, Foley PN, Kay BH, 1997. The importance of surface versus subterranean mosquito breeding during winter in north Queensland. *Arbovirus Res Aust* 7: 240–242.
3. Russell B, Kay B, 1999. Calibrated funnel trap for quantifying mosquito (Diptera: Culicidae) abundance in wells. *J Med Entomol* 36: 851–855.
4. Tun-Lin W, Kay BH, Barnes A, 1995. Understanding productivity, a key to *Aedes aegypti* surveillance. *Am J Trop Med Hyg* 53: 595–601.
5. Kay BH, Prakash G, Andre RG, 1995. *Aedes albopictus* and *Aedes (Stegomyia)* species in Fiji. *J Am Mosq Control Assoc* 11: 230–234.
6. Russell BM, Muir LE, Weinstein P, Kay BH, 1996. Surveillance of the mosquito *Aedes aegypti* and its biocontrol with the copepod *Mesocyclops aspericornis* in Australian wells and gold mines. *Med Vet Entomol* 10: 155–160.
7. Hanna JN, Ritchie SA, Merritt AD, van den Hurk AF, Phillips DA, Serafin IL, Norton RE, McBride WJH, Gleeson FV, Poidinger M, 1998. Two contiguous outbreaks of dengue type 2 in north Queensland. *Med J Aust* 168: 221–225.
8. Lee DJ, Hicks MM, Griffiths M, Marks EN, Bryan JH, Russell RC, 1989. *The Culicidae of the Australasian Region. Entomology Monograph No. 2.* Canberra: Australian Government Publishing Service Press.
9. Kay BH, Barker-Hudson P, Stallman ND, Wiemers MA, Marks EN, Holt PJ, Muscio M, Gorman BM, 1984. Dengue fever. Reappearance in northern Queensland after 26 years. *Med J Aust* 140: 264–268.
10. Laird M, 1988. *The Natural History of Larval Mosquito Habitats.* London: Academic Press.
11. Tinker ME, 1974. *Aedes aegypti* larval habitats in Surinam. *Bull Pan Am Health Organ* 8: 293–301.
12. Focks DA, Chadee DD, 1997. Pupal survey: an epidemiologically significant surveillance method for *Aedes aegypti*: an example using data from Trinidad. *Am J Trop Med Hyg* 56: 159–167.
13. Tun-Lin W, Kay BH, Barnes A, 1995. The premise condition index: a tool for streamlining surveys of *Aedes aegypti*. *Am J Trop Med Hyg* 53: 591–594.
14. Merritt RW, Dadd RH, Walker ED, 1992. Feeding behavior, natural food, and nutritional relationships of larval mosquitoes. *Annu Rev Entomol* 37: 349–376.
15. Watson TM, Kay BH, 1998. Vector competence of *Aedes notoscriptus* (Diptera: Culicidae) for Ross River virus in Queensland, Australia. *J Med Entomol* 35: 104–106.
16. Focks DA, Brenner RJ, Hayes J, Daniels, 2000. Transmission thresholds for dengue in terms of *Aedes aegypti* pupae per person with discussion of their utility in source reduction efforts. *Am J Trop Med Hyg* 62: 11–18.