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Spatial distribution of *Aedes aegypti* and *Aedes albopictus* in relation to geo-ecological features in South Andaman, Andaman and Nicobar Islands, India

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Abstract

The study was undertaken in South Andaman district, comprising three tehsils, *viz.* Port Blair, Ferrargunj and Little Andaman Tehsils, respectively. Intensive pupal infestation surveys were carried out along the National Highway (NH 223), the main passenger and trade route, referred to as Great Andaman Trunk Road. Sampling locations at every 3 km were geo-referenced with global positioning system unit. A total of 17314 water collections were examined from 29 locations across the South Andaman district, among which 1021 (5.9%) were colonized by immature stages of *Aedes albopictus*, *Aedes aegypti* and other mosquito species. *Ae. aegypti* were found in 12 locations, showing higher infestation in the densely built Aberdeen Bazaar. Breeding populations of *Ae. albopictus* were observed in 27 sampling locations. Both the species were not recorded in two Northern localities. In the areas where both the species are present, they were often found in the same developmental sites, suggesting convergent habitat selection. The most frequently encountered man-made, artificial and natural developmental sites were fixed cement tanks, plastic drums, plastic cans, metal drums, metal pots, discarded tires, coconut shells, leaf axils and tree holes. *Ae. aegypti* and *Ae. albopictus* were observed in varying proportions in Port Blair and Ferrargunj Tehsils, while the former species appeared to be absent in Little Andaman. This study elucidates the spatial distribution of *Ae. aegypti* and *Ae. albopictus* with preponderance of the latter species, pointing towards arboviral transmission and assumes public health importance in South Andaman district, endemic for dengue.

Keywords: arboviruses, vectors, larval ecology, topography, A&N islands, India

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Introduction

Aedes aegypti and *Aedes albopictus* are potential vectors to humans of several arboviral pathogens (Shroyer, 1986; Hawley, 1988; CDC, 2016). *Ae. aegypti* is the main vector of dengue virus (DENV), chikungunya virus (CHIKV) and yellow fever virus (Kow *et al.*, 2001; Gubler, 2002). Although *Ae. albopictus* is capable of transmitting a large number of arboviruses (Mitchell, 1995), the species has generally been considered as a secondary vector because of its lack of host specificity (Gratz, 2004). However, after the emergence of CHIKV epidemics involving *Ae. Albopictus*, its vector status has been re-examined in countries adjoining the Indian Ocean (Vazeille *et al.*, 2007; Delatte *et al.*, 2008*a*, *b*; Leroy *et al.*, 2009; Paupy *et al.*, 2009) and Europe (Charrel *et al.*, 2008). The involvement of this mosquito species in pandemics of chikungunya made it necessary to examine the current distribution and vector scenario for potential outbreaks (Seneviratne *et al.*, 2007; Pagès *et al.*, 2009; Pistone *et al.*, 2009; Yoosuf *et al.*, 2009).

Although the native geographic range of *Ae. aegypti* was sub-Saharan Africa (Mattingly, 1957), at present it has a

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wide distribution range between 45°N and 35°S. This mosquito species infests all countries and occurs in a wide range of environments from sylvan to urban. Unlike *Ae.aegypti*, *Ae. albopictus* is native to Southeast Asia (Smith, 1956), where it is a proven vector of filarial worms and dengue (Hawley, 1988). It has been reported in the African continent, where it was first detected in South Africa (Cornel & Hunt, 1991), and later spread prolifically in Nigeria (Savage *et al*., 1992). Over the next few decades, *Ae. albopictus* spread to several Central African countries (Paupy *et al*., 2009), where it has been reported to colonize urban locales up to a latitude of 6° N (Simard *et al*., 2005). *Ae. albopictus* is now established in numerous countries throughout the USA, Europe, Africa (Medlock *et al*., 2012; Ngoagouni *et al*., 2015; ECDC, 2016) and Oceania (Nicholson *et al*., 2014) and the predominant dispersal mechanisms implicated are intercontinental trade and shipments of tires.

The geographical distributions of *Ae. aegypti* and *Ae. albopictus* overlap in tropical Asia and the USA. Spatial and ecological co-existence of these two species has been reported in different parts of the world and the larvae sometimes share common breeding sites (Simard *et al*., 2005; Chen *et al*., 2006). In South American and Southeast Asian countries where these species are sympatric, they separate in various habitats under the influence of environmental factors (Braks *et al*., 2003; Rey *et al*., 2006; Tsuda *et al*., 2006). *Ae. aegypti* is adapted to the domestic environment, and therefore, its abundance is positively associated with increasing urbanization, while *Ae. albopictus* is associated with vegetation, and its abundance is reported to have been adversely affected by urbanization (Tsuda & Takagi, 2001; Rey *et al*., 2006; Tsuda *et al*., 2006). *Ae. albopictus* has also the ability to colonize urban habitats, especially when *Ae. aegypti* is absent (Delatte *et al*., 2008*a*). Spatial overlap of these two mosquito species is assumed to result in a competitive interaction. Displacement of *Ae. aegypti* has been observed post-*Ae. albopictus* invasion in southeastern USA and Brazil (Lounibos, 2002; Juliano & Lounibos, 2005) and is hypothesized to have occurred in La Reunion and Mayotte (Bagny *et al*., 2009*a*, *b*). On the contrary, available reports in Asia suggests that *Ae. aegypti* has an overall competitive edge over *Ae. albopictus* in urban settings (Gilotra *et al*., 1967).

Both the species have been reported to be container breeding mosquitoes that are proximal to humans. *Ae. aegypti* inclines to predominate in densely populated urban settings and commonly found indoors, breeding in artificial water containers used for storage and a variety of discarded containers of fresh water (Christophers, 1960). *Ae. albopictus* prefers natural water-holding containers, such as tree holes, leaf axils and artificial containers, such as discarded tin cans and tires (Hawley, 1988). On the other hand, in areas where both the species co-exist, their larvae are often found together in the same larval breeding site (Braks *et al*., 2003).

Ae. aegypti and *Ae. albopictus* have been known for a long time in Andamans (Barraud, 1934). The occurrence of *Ae.aegypti* in the Andaman archipelago has been documented (Nagpal & Sharma, 1983). Since then it has become significantly present and distributed widely throughout the urban agglomeration of Port Blair (Shriram & Sehgal, 1999) and has been observed to infiltrate into the peri-urban and rural areas (Shriram *et al*., 2008). *Ae. albopictus* infestation has been observed in the urban peri-urban areas adjoining Port Blair (Shriram *et al*., 2009). Thus, the urban and peri-urban areas are infested with both of these mosquito species and this poses a public health threat. These mosquito species were probably involved during the past outbreaks of chikungunya (Manimunda *et al*., 2007) and dengue (Vijayachari *et al*., 2011). Prevailing scenario necessitates the generation of in-depth information on the distribution pattern of these mosquito species in South Andaman, where dengue is endemic and sporadic cases of chikungunya regularly occurring after the 2006 outbreak (Manimunda *et al*., 2007).

The goal of the present study was to assess the distribution of *Ae. aegypti* and *Ae. albopictus* across the heterogeneous landscapes of South Andaman Island. The information generated would help in classifying areas by risk of dengue and chikungunya transmission for public health preparedness and to develop effective vector control measures.

Materials and methods

Study area

The study was undertaken in South Andaman district. The district comprises of three administrative subunits called tehsils, *viz*. Port Blair Tehsil (PBT), Ferrargunj Tehsil (FGT) and Little Andaman Tehsil (LAT). More than 87% (2613.53 km^2) of the total land area of 2980 km^2 of the island is forest covered uninhabited/sparsely populated areas, 340.37 km^2 (11.4%) is occupied by rural villages and 26.10 km^2 (0.9%) by urban areas. The entire district of South Andaman was classified into four topographies, *viz*. (1) densely built urban – thickly populated with residential and commercial buildings; (2) low-vegetation coverage – thinly populated with short vegetation, mostly grass; (3) medium-vegetation coverage/fringe area – sparsely populated with short vegetation, shrubs and small trees, and (4) high-vegetation coverage – sparsely populated forested area with tall vegetation/trees. Demarcation of these topographies was done with the aid of satellite images.

Entomological infestation surveys

The entomological surveys were conducted during the period September and December 2012 in localities spread along the National Highway 223 (NH223), which is the main passenger and trade route of Andaman Islands. Great Andaman Trunk Road (GATR) is the popular name for this highway, which traverses through the study area of South Andaman district and connects Port Blair in South Andaman district to Mayabunder in North and Middle Andaman district.

In order to understand the geographic distribution of *Ae. aegypti* and *Ae. albopictus*, intensive pupal infestation surveys were carried out along the GATR. One starting point was identified on the part of GATR within Port Blair town and from there the survey team followed the road. Sampling locations were selected at every 3 km. Each sampling location was geo-referenced using a global positioning system hand-held device (eTrex LegendTM, Garmin International Ltd., Olathe, Kansas, USA) and assigned a unique identifier. The team then inspected an area of 1.5 km radius around the reference point on the GATR. A similar procedure was followed in LAT.

The larval sampling procedures (WHO, 2011) adopted were qualitative. The basic sampling unit was a house or a premise, and at each sampling unit, the permission of the owner/occupant was obtained. All the sampling units were systematically searched for water-holding containers, and the detected containers were examined for the presence of mosquito pupae by trained insect collectors.

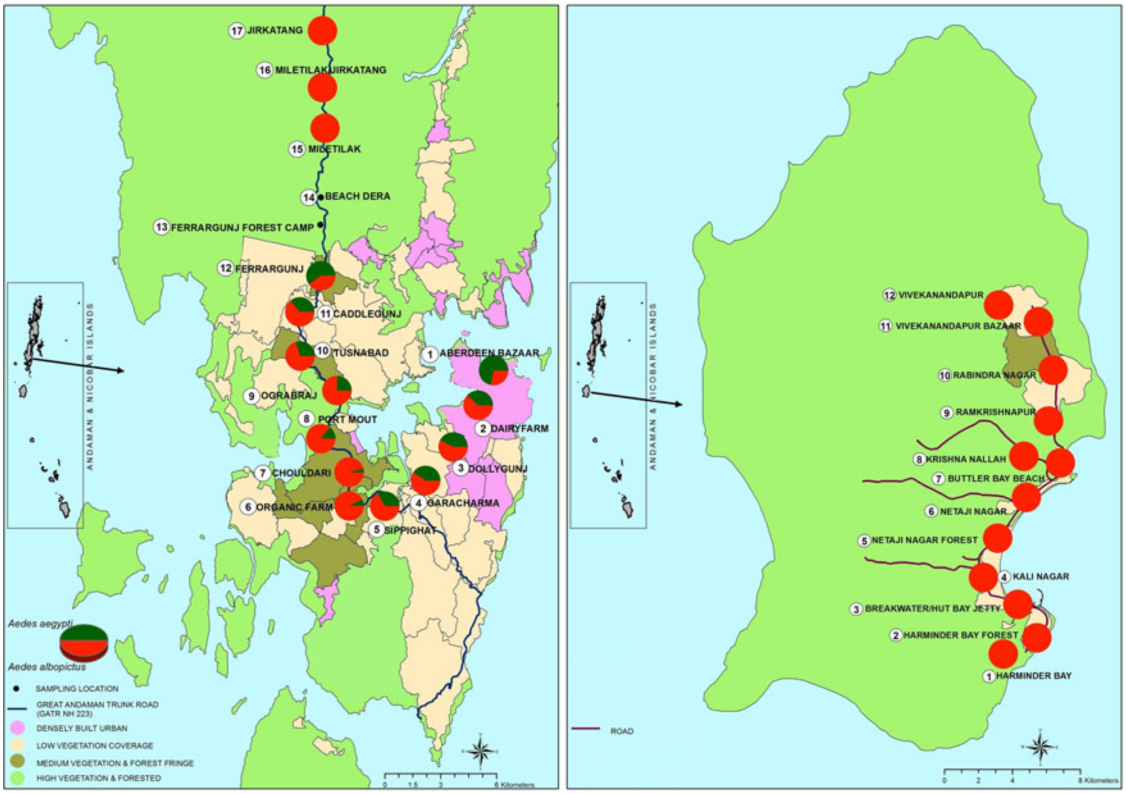

Fig. 1. Map showing the sampling locations for *Aedes* infestation surveys (17 locations commencing from Aberdeen Bazaar to Jirkatang covering Port Blair and Ferrargunj Tehsil, a distance of 43 km; 12 sampling locations, along a stretch of 28 km road, which connects Harminder Bay and V K Pur in Little Andaman Tehsil) and relative abundance of *Aedes aegypti* (green) and *Aedes albopictus* (red) in South Andaman district.

The contents of the water-holding containers where mosquito breeding was detected were strained through a sieve, and the sieved contents were re-suspended in a small amount of clean water in a white enamel/plastic tray. Sweep nets were used for larger containers. All the pupae retrieved from a single habitat were transferred to a labelled plastic container. These were brought to the Centre's laboratory and the pupae were raised to adults. Emerged adults were identified using standard taxonomic keys (Barraud, 1934).

Aedes infestation surveys were done in 17 sampling locations along a stretch of 43 km on the GATR covering both PBT and FGT. Further north, the GATR traverses through the reserve area for the Jarawa tribe, and on this part, a stretch of 47 km could not be covered as no intervention in this area is allowed. In Little Andaman, infestation surveys were done in 12 sampling locations, along a stretch of 28 km on the road that connects Harminder Bay and Vivekanand Pur (fig. 1). The description of sampling locations in South Andaman district is furnished in table 1.

Results

Geographic distribution of Ae. aegypti *and* Ae. albopictus *in South Andaman*

A total of 17,314 water-holding containers were detected in the 29 sampling locations across the South Andaman district (fig. 1), and among these, 1021 (5.9%) were colonized by immature stages of *Ae. albopictus*, *Ae. aegypti* and other mosquito species. It was observed that 357 (2.1%) containers were colonized by *Ae. albopictus* and or *Ae. aegypti* (tables 1 and 3). Other mosquito species found breeding were *Aedes subalbopictus*, *Stegomyia* w-*albus*, *Aedes malayensis*, *Aedes* spp, *Culex* (*Eumelanomyia*) *brevipalpis*, *Culex* (*Lophoceraomyia*) *minor*, *Culex* (*Lophoceraomyia*) *mammalifer*, *Culex* (*Culiciomyia*) *pallidothorax*, *Culex* (*Culiciomyia*) *fragilis*, *Culex* (*Culiciomyia*) *nigropunctatus*, *Anopheles* (*Cellia*) *sundaicus*, *Armigeres* (*Armigeres*) *joloensis*, *Armigeres* (*Armigeres*) *kuchingensis*, *Toxorhynchites* spp., *Verralina* (*Neomacleaya*) *andamanensis*, *Verralina* sp., *Uranotaenia* (*pseudoficalbia*) *nivipleura*, *Uranotaenia* sp, *Lutzia* (*Metalutzia*) *halifaxii*, *Malaya genurostris*, *Tripteroides* (*Rachionotomyia*) *aranoides*, *Heizmannia* (*Mattinglyia*) *discrepans*, *Heizmannia* sp and *Christophersiomyia thomsoni*.

Out of the 29 locations sampled across the three Tehsils of South Andaman district, *Ae. albopictus* were detected in 27 locations including all the locations in Little Andaman and 15 of the 17 locations in South Andaman Island. Neither *Ae. albopictus* nor *Ae. aegypti* was detected in the two northernmost locations in FGT of South Andaman. *Ae. aegypti* was absent in the entire LAT (fig. 1 and table 1). While *Ae. aegypti* breeding sites were found in 2–18% of the premises in localities where it existed, *Ae. albopictus* breeding sites were found in 2.0–24.0% of the premises. For *Ae. aegypti*, the highest premise and container index was in Garacharma in South Andaman. This locality is a suburban area of Port Blair. In the case of *Ae. albopictus*, the highest premise and container index was in Chouldari in FGT

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Table 1. Description of study communities, distribution and prevalence of developmental sites for *Aedes albopictus* and *Aedes aegypti* at sampling locations in South Andaman district.

				Inspected		*Ae. aegypti* positive				*Ae. albopictus* positive			
No	Localities	Tehsil	Description of community	Containers	Premises	Containers	(%)	Premises	(%)	Containers	(%)	Premises	(%)
13	Forest Check Post	FGT	HVC	436	100	0		0		0		0	
14	Beach Dera	FGT	HVC	583	101	0		0		0		0	
15	Mile Tilak	FGT	HVC	505	100	0		0		2		2	
16	Jinghanallah/Mile Tilak	FGT	HVC	459	100	0		0		2		2	
17	Jirkatang	FGT	HVC	600	100	0		0		3		3	
22	Nethaji Nagar Forest	LAT	HVC	207	55	0		0		5		5	
				2790	556	0	0.00	0	0.00	12	0.43	12	2.16
3	Dollygunj/Old Pahargaon	PBT	LVC	651	70	13		13		14		10	
4	Garacharma	PBT	LVC	1290	127	21		19		14		13	
5	Sippighat	PBT	LVC	1093	119	8		7		16		14	
18	Harminder Bay	LAT	LVC	263	50	0		0		12		12	
20	Hut Bay Jetty/Break water	LAT	LVC	291	50	0		0		5		5	
21	Kali Nagar	LAT	LVC	297	51	0		0		12		12	
23	Nethaji Nagar	LAT	LVC	231	51	0		0		4		4	
				4116	518	42	1.02	39	7.53	77	1.87	70	13.51
6	Organic Farm	PBT	MVC	868	120	2		2		9		7	
7	Chouldari	FGT	MVC	883	117	3		3		20		18	
8	Port Mout	FGT	MVC	1093	118	6		6		18		17	
9	Ograbraj	FGT	MVC	1045	117	8		7		10		10	
10	Tushnabad	FGT	MVC	1015	110	7		7		19		16	
11	Caddlegunj	FGT	MVC	893	100	6		6		11		11	
12	Ferrargunj	FGT	MVC	1275	100	14		11		18		17	
19	Harminder Bay Forest	LAT	MVC	201	50	0		0		8		8	
24	Krishna Nallah	LAT	MVC	184	53	0		0		3		3	
25	Butler Bay Beach	LAT	MVC	216	50	0		0		7		7	
26	R K Pur	LAT	MVC	230	52	0		0		7		7	
27	Rabindra Nagar	LAT	MVC	266	52	0		0		9		9	
28	V K Pur Bazaar	LAT	MVC	258	50	0		0		4		4	
29	V K Pur	LAT	MVC	301	50	0		0		2		2	
				8728	1139	46	0.53	42	3.69	145	1.66	136	11.94
1	Aberdeen Bazaar	PBT	DBU	942	100	3		3		10		10	
2	Dairy Farm	PBT	DBU	738	109	9		9		13		13	
				1680	209	12	0.71	12	5.74	23	1.37	23	11.00

Table 2. Container and premise indices for *Aedes aegypti* and *Aedes albopictus* in the four ecological settings.

	Container index [% (95% CI)]		Premise index [% (95% CI)]	
Ecological zone	*Ae. aegypti*	*Ae. albopictus*	*Ae. aegypti*	*Ae. albopictus*
Densely built urban	0.71 (0.38, 1.28)	1.37 (0.89, 2.08)	5.74 (3.14, 10.06)	11.00 (7.25, 16.24)
Low vegetation	1.02 (0.75, 1.39)	1.87 (1.49, 2.34)	7.53 (5.47, 10.24)	13.51 (10.75, 16.83)
Medium vegetation	0.53 (0.39, 0.710)	1.66 (1.41, 1.96)	3.69 (2.70, 5.00)	11.94 (10.14, 14.00)
High vegetation	0.00 (0.00, 0.17)	0.43 (0.23, 0.77)	0.00 (0.00, 0.86)]	2.16 (1.17, 3.85)

of South Andaman Island. This area is a rural area abutting forests (table 1).

The overall infestation, judged by both the container index and premise index, was the highest in the low-vegetation areas and the lowest in the high-vegetation areas both for *Ae. aegypti* and *Ae. albopictus*. In all the ecological zones, the infestation levels of *Ae. albopictus* was higher than that of *Ae. aegypti*. This difference was the most pronounced in medium-vegetation areas, where both the container and premise indices for *Ae. albopictus* were about three times those for *Ae. aegypti* (table 2).

Ae. albopictus and *Ae. aegypti* colonized a variety of man-made, artificial and natural breeding places (table 3). The volume of water in breeding sites ranged from 2 ml to 1000 l. A total of 100 water containers were found to have breeding of *Ae. aegypti*, and among these, 69 (69%) were cement tanks, drums or plastic cans. Another 20 (20%) were coconut shells, discarded tires, buckets, tin cans or metal pots. Thus, vast majority of *Ae. aegypti* breeding sites are man-made medium and large water containers and unattended or abandoned water-holding objects littering the house premises. A total of 257 water-holding containers were colonized by *Ae. albopictus*, and among these, 118 (46%) were constituted by drums, cans and tree holes. Another 96 (38%) were constituted by coconut shells, tires, buckets, flower vases and miscellaneous containers.

Both species of mosquitoes were frequently found together in the same larval habitat (fig. 1, table 3). There were a total of 330 water-holding containers in which *Ae. aegypti*, *Ae. albopictus* or both were breeding, and among these, 28 (8.5%) had the breeding of both the species. These 28 water-holding containers, in which both the species were breeding simultaneously constituted 0.2% of the total containers inspected. The abundance of breeding sites for *Ae. albopictus* only loosely correlated with abundance of breeding sites for *Ae. aegypti* (Pearson's correlation coefficient =0.1536, df = 17, $P = 0.119764$, single-sided test, $P < 0.05$).

Discussion

We assessed the pupal infestation of *Ae. aegypti* and *Ae. albopictus* in various types of water-holding containers that support the breeding of these two species, across heterogeneous landscapes in South Andaman, endemic for dengue and sporadic cases of chikungunya.

Ae. albopictus was present in all the three Tehsils, while *Ae. aegypti* was totally absent in Little Andaman Island (LAT). In PBT and FGT, the two species co-existed, but their relative proportions and spatial distribution differed, which could probably be attributed to the differences in density of vegetation and buildings.

Ae. aegypti was present from the southernmost sampling location (location 1 – Aberdeen Bazaar) through location 12 (Ferrargunj). In Aberdeen Bazaar (densely built urban area), the relative proportion of *Ae. aegypti* was more compared with *Ae. albopictus*. Right through these sampling locations (1–12), both of these species co-existed, though their relative proportions varied. In sampling location 1, which is the most urbanized area, *Ae. aegypti* greatly predominated. As we moved away from urban Port Blair, this predominance of *Ae. aegypti* gradually decreased up to sampling location 7 (Chouldari), where *Ae. albopictus* greatly predominated. From Port Blair to Chouldari, on either side of the GATR, the vegetation density increases gradually, while the density of human dwellings decreases. An urban predilection of *Ae. aegypti* and the opposite for *Ae. albopictus* were evident in this trend.

As we move further up on the GATR from Chouldari, though the distance from urban Port Blair keeps increasing, the relative proportion of *Ae. aegypti* starts picking up to reach a further peak at Ferrargunj. This might look paradoxical, but Ferrargunj is a fairly populated village and is close to some of the densely populated areas on the opposite bank of the estuary that forms the northern boundary of Port Blair. GATR, when it winds around the estuary, reaches the farthest point from densely populated areas between Organic Farm and Chouldari (sampling locations 6 and 7). The direct distance from human dwellings seems to be a strong determinant of the relative proportion of *Ae. aegypti* and *Ae. albopictus*. The present data show that *Ae. albopictus* has established breeding populations all across South Andaman district. Even in areas where there was co-existence of *Ae. albopictus* and *Ae. aegypti*, which is confined to the areas around the part of GATR that goes around the estuary, *Ae. albopictus* predominated except in the two most densely populated areas of Port Blair and Ferrargunj. This indicates that this highly invasive mosquito species is the single dominant species in forested and medium-vegetation tracts, while it co-exists with *Ae. aegypti* in low-vegetation and densely built urban areas. Both of these species were absent at locations 14 (Beach dera) and 15 (Mile Tilak). *Ae. aegypti* is entirely absent in the isolated Little Andaman Island, the southernmost island in the Andaman archipelago.

Recent observations, on host feeding behaviour of *Ae.aegypti* and *Ae. albopictus* in South Andaman, suggest predominance of anthropophilism. The former species was reported to feed predominantly on human blood in the densely built urban, low-vegetation and medium-vegetation coverage. While the latter species showed high degree of anthrophilism in the densely built urban setting, which gradually decreased from low-vegetation to the highly vegetated forested tracts. This indicates plasticity in feeding across these landscapes (Sivan *et al.*, 2015). In addition to other eco-biological variables, the difference in feeding behaviour could probably be attributed to the difference in spatial distribution of *Ae. aegypti* and *Ae. albopictus* across the sequence of heterogeneous landscapes (densely built urban to forested and *vice versa*) and co-existence of these two species within the same geographical region.

Table 3. Container preferences of *Aedes albopictus* and *Aedes aegypti* in South Andaman district.

	Container type	Number positive/number inspected (%)		
		Ae. aegypti	*Ae. albopictus*	No. shared
1	Bamboo joints	0/97 (0.0)	1/97 (1.0)	0/97 (0.0)
2	Basins	1/248 (0.40)	2/248 (0.8)	1/248 (0.40)
3	Bottles	1/682 (0.2)	2/682 (0.3)	1/682 (0.2)
4	Coconut shells	6/977 (0.6)	20/977 (2.0)	2/977 (0.2)
5	Discarded tires	2/259 (0.8)	11/259 (4.2)	0/259 (0.0)
6	Disposable cups	0/368 (0.0)	6/368 (1.6)	0/368 (0.0)
7	Discarded tin	0/45 (0.0)	1/45 (2.2)	0/45 (0.0)
8	Fixed cement tank	18/762 (2.4)	5/762 (0.7)	2/762 (0.3)
9	Flower vase	0/654 (0.0)	12/654 (1.8)	0/654 (0.0)
10	Grinding stone	1/55 (1.8)	3/55 (5.5)	0/55 (0.0)
11	Ground pools	1/717 (0.1)	0/717 (0.0)	0/717 (0.0)
12	Jars	0/156 (0.0)	4/156 (2.6)	0/156 (0.0)
13	Leaves	0/998 (0.0)	1/998 (0.1)	0/998 (0.0)
14	Leaf axils	1/1141 (0.0)	3/1141 (0.3)	0/1141 (0.0)
15	Metal bucket	3/670 (0.5)	11/670 (1.6)	2/670 (0.3)
16	Metal drums	10/690 (1.5)	20/690 (2.9)	1/690 (0.1)
17	Metal pot	4/210 (1.9)	8/210 (3.8)	2/210 (1.0)
18	Miscellaneous	1/509 (0.2)	19/509 (3.7)	1/509 (0.2)
19	Pine apple leaf axils	1/151 (0.7)	1/151 (0.7)	0/151 (0.0)
20	Plastic bucket	2/1288 (0.2)	11/1288 (0.9)	1/1288 (0.1)
21	Plastic cans	7/1061 (0.7)	26/1061 (2.5)	4/1061 (0.4)
22	Plastic container	1/761 (0.01)	12/761 (1.6)	1/761 (0.01)
23	Plastic drums	34/1674 (2.0)	26/1674 (1.6)	8/1674 (0.5)
24	Plastic pots	0/70 (0.0)	2/70 (2.9)	0/70 (0.0)
25	Plates	0/197 (0.0)	1/197 (0.5)	0/197 (0.0)
26	Rock hole	0/139 (0.0)	1/139 (0.7)	0/139 (0.0)
27	Scrap iron	0/140 (0.0)	1/140 (0.7)	0/140 (0.0)
28	Tin cans	3/545 (0.6)	20/545 (3.7)	1/545 (0.2)
29	Tree holes	1/993 (0.1)	26/993 (2.6)	0/993 (0.0)
30	Vehicle tracts	0/74 (0.0)	1/74 (1.4)	0/74 (0.0)
31	Water pipes	1/86 (1.2)	1/86 (1.2)	1/86 (1.2)
32	Wells	1/117 (0.9)	0/117 (0.0)	0/117 (0.0)

The key containers/habitats supporting breeding of both species are different, i.e. *Ae. aegypti* prefers larger water-holding containers, while *Ae. albopictus* prefers smaller containers for breeding. Both these species were also found in basins, bottles, coconut shells, fixed cement tanks, metal drums, metal pots, plastic drums, tin cans and water pipes, indicative of convergent habitat selection. Similar phenomenon has been reported in Singapore (Chan *et al*., 1971*a*, *b*), Brazil and the USA (Braks *et al*., 2003) and Cameroon (Simard *et al*., 2005; Kamgang *et al*., 2010).

Two broad categories of containers were the predominant breeding habitats of both the mosquito species. These were large and medium unattended or abandoned man-made containers and objects littering the dwelling premises, such as coconut shells and tires. However, large- and medium-sized and unattended containers formed a larger proportion of *Ae. aegypti* breeding habitats as compared with the breeding habitats of *Ae. albopictus*. On the contrary, objects littering the environment and natural water-holding sites constituted a larger proportion of the breeding habitats of *Ae. albopictus*. This implies that the culprit in *Ae. aegypti* infestation are the poorly maintained large- and medium-sized containers in the community. This behaviour of the community is probably the result of lack of risk perception of the community and a possible control strategy could be increasing the risk perception through awareness programmes. The other social behaviour that poses the risk of *Aedes* mosquito infestation is poor environmental hygiene resulting in the environment being littered with objects that could hold water and facilitate mosquito breeding. The solution for this also is awareness programmes for improving environmental hygiene. Part of the littering might be the results of careless habits of traders and small business establishments engaged in coconut trade and manufacture of *Copra* and tire vendors and vehicle repair garages. This probably has to be addressed through legislation or administrative action. Unplanned urbanization, intermittent water supply and lack of waste management facilitate burgeoning of water-holding containers, eventually facilitating to propagation of *Aedes* spp.

The habitats in LAT were similar to these forested northerly areas of South Andaman and the breeding was confined to *Ae. albopictus*. Because the 12 sampling locations in Little Andaman Island (LAT) and three northerly located sampling locations, *viz*. Mile Tilak, Mile Tilak/Jirkatang and Jirkatang is more forested than the other sampling localities, may provide a more favourable environment for *Ae. albopictus* and hence the dominance of this invasive mosquito species. Trade through the GATR road network could probably be the main source of dissemination of *Ae. albopictus*. Discarded tires is an important breeding habitat of *Aedes* mosquitoes as observed earlier during an outbreak of dengue in Havelock island, a tourist destination close to South Andaman (Sivan *et al*., 2016).

It has been observed in Sri Lanka that plastic net covers used in ground-level cemented water storage tanks resulted in significant reduction of *Aedes* mosquito breeding. This

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strategy was both user-friendly and cost-effective (Kusumawathie *et al*., 2009). This approach appears to be feasible in South Andaman district, if awareness is created regarding the advantage of covering such water-holding containers among the community at risk.

The difference in spatial distribution of *Ae*. *aegypti* and *Ae*. *albopictus* appears to be significant for occurrences of dengue in South Andaman. Out of 80–151 annual dengue cases from 2010 to 2014 (RMRC unpublished) in South Andaman (PBT and FGT), 77.8% and 14.1% of the cases were reported from the densely built urban and low-vegetation coverage areas. While from the medium-vegetation and high-vegetation areas, 6.3% and 1.9% cases were reported. Although both these species co-exist in varying proportions in South Andaman and probably did play a role in the emergence of dengue, there has been no direct evidence of their respective roles in the transmission of DENV in the islands. Therefore, it is imperative to monitor the infestation of *Ae*. *aegypti* and *Ae*. *albopictus* for potential outbreaks of dengue in the region.

As opined by Gubler (2003), invasion and further spread of *Ae*. *albopictus* into the densely built urban areas of Port Blair urban agglomeration, where *Ae*. *aegypti* is widely prevalent (Shriram & Sehgal, 1999) could have consequences of public health importance. Anthropophilism coupled with its ability to colonize urban and peri-urban areas render *Ae*. *albopictus* as a possible bridge vector that perhaps increases the risk of introduction and facilitate transmission of arboviruses (Sivan *et al*., 2015). Our recent investigations implicated the involvement of this mosquito species in an outbreak of dengue in the tourist destination, Havelock Island (Sivan *et al*., 2016). Therefore, *Ae*. *albopictus* is of public health concern.

Ae. *albopictus* invasion leading to decline in abundance and competitive displacement have been observed (Lounibos, 2002). Therefore, future investigations in this region should consider this phenomenon, which provides an opportunity to explore competitive displacement and/or niche segregation between the widely prevalent *Ae*. *aegypti* populations and the invasive *Ae*. *albopictus* populations; but quite recently, our experience at Havelock shows that, even if *Ae*. *albopictus* helps to eliminate *Ae*. *aegypti*, that is not going to be beneficial from a public health point of view as *Ae*. *albopictus* is capable of assuming the role of dengue vector and is much difficult to control than *Ae*. *aegypti* (Sivan *et al*., 2016). Close surveillance of this probable invasion process, in this part of the country would undoubtedly advance our knowledge for the development and implementation of vector control measures.

In conclusion, *Ae*.*aegypti* and *Ae*. *albopictus* was observed in varying proportions in PBT and FGT, while *Ae*. *aegypti* appears to be absent in LAT. This survey depicts the spatial distribution of *Ae*. *aegypti* and *Ae*. *albopictus* with preponderance of the latter species, pointing towards arboviral transmission and assumes public health importance in South Andaman district, endemic setting for dengue and sporadic reports of chikungunya. The data generated on developmental sites and spatial distribution should be useful for the National Vector Control Programme.

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References

Bagny, L., Delatte, H., Elissa, N., Quilici, S. & Fontenille, D. (2009*a*) Aedes (Diptera: Culicidae) vectors of arboviruses in Mayotte (Indian Ocean): distribution area and larval habitats. *Journal of Medical Entomology* **46**, 198–207.

Bagny, L., Delatte, H., Quilici, S. & Fontenille, D. (2009*b*) Progressive decrease in *Aedes aegypti* distribution in Reunion Island since the 1900s. *Journal of Medical Entomology* **46**, 1541–1545.

Barraud, P.J. (1934) *The Fauna of British India Including Burma and Ceylon. Diptera: Culicidae, Tribes Megarhinini and Culicini*, vol. **V**. London, Taylor and Francis, pp. 1–452.

Braks, M.A., Honório, N.A., Lourençqo-De-Oliveira, R., Juliano, S.A. & Lounibos, L.P. (2003) Convergent habitat segregation of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) in southeastern Brazil and Florida. *Journal of Medical Entomology* **40**, 785–794.

CDC (2016) Division of Vector Borne Diseases. Available online at http://www.cdc.gov/ncezid/dvbd/ (accessed 15 February 2016).

Chan, K.L., Chan, Y.C. & Ho, B.C. (1971*a*) *Aedes aegypti* (L.) and *Aedes albopictus* (Skuse) in Singapore city. 2. Larval habitats. *Bulletin of World Health Organization* **44**, 629–633.

Chan, Y.C., Chan, K.L. & Ho, B.C. (1971*b*) *Aedes Aegypti* (L.) and *Aedes Albopictus* (Skuse) in Singapore City. 1. Distribution and density. *Bulletin of World Health Organization* **44**, 617–627.

Charrel, R.N., de Lamballerie, X. & Raoult, D. (2008) Seasonality of mosquitoes and chikungunya in Italy. *The Lancet Infectious Disease* **8**, 5–6.

Chen, C.D., Nazni, W.A., Lee, H.L., Seleena, B., MohdMasri, S., Chiang, Y.F. & Sofian-Azirun, M. (2006) Mixed breeding of *Aedes aegypti* (L.) and *Aedes albopictus* Skuse in four dengue endemic areas in Kuala Lumpur and Selangor, Malaysia. *Tropical Biomedicine* **23**, 224–227.

Christophers, S.R. (1960) *Aedes aegypti (L) the Yellow Fever Mosquito: Its Life History, Bionomics and Structure*. Cambridge, UK, Cambridge University Press.

Cornel, A.J. & Hunt, R.H. (1991) *Aedes albopictus* in Africa? First records of live specimens in imported tires in Cape Town. *Journal of American Mosquito Control Association* **7**, 107–108.

Delatte, H., Dehecq, J.S., Thiria, J., Domerg, C., Paupy, C. & Fontenille, D. (2008*a*) Geographic distribution and developmental sites of *Aedes albopictus* (Diptera: Culicidae) during a Chikungunya epidemic event. *Vector Borne Zoonotic Diseases* **8**, 25–34.

Delatte, H., Paupy, C., Dehecq, J.S., Thiria, J., Failloux, A.B. & Fontenille, D. (2008*b*) *Aedes albopictus*, vector of chikungunya and dengue viruses in Reunion Island: biology and control. *Parasite* **15**, 3–13.

ECDC (2016) *Aedes albopictus*. Available online at http://ecdc.europa.eu/en/healthtopics/vectors/mosquitoes/Pages/aedes-albopictus.aspx (acceded 31 January 2016).

Gilotra, S.K., Rozeboom, L.E. & Bhattacharya, N.C. (1967) Observations on possible competitive displacement between populations of *Aedes aegypti* Linnaeus and *Aedes albopictus* Skuse in Calcutta. *Bulletin of World Health Organization* **37**, 437–446.

Gratz, N.G. (2004) Critical review of the vector status of *Aedes albopictus*. *Medical and Veterinary Entomology* **18**, 215–227.

Gubler, D.J. (2002) Epidemic dengue/dengue hemorrhagic fever as a public health, social and economic problem in the 21st century. *Trends in Microbiology* **10**, 100–103.

Gubler, D.J. (2003) *Aedes albopictus* in Africa. *Lancet Infectious Disease* **3**, 751–752.

Hawley, W.A. (1988) The biology of *Aedes albopictus*. *Journal of American Mosquito Control Association* **4**, 1–40.

Juliano, S.A. & Lounibos, L.P. (2005) Ecology of invasive mosquitoes: effects on resident species and on human health. *Ecology Letters* **8**, 558–574.

Kamgang, B., Youta Happi, J., Boisier, P., Njiokou, F., Hervé, J.P., Simard, F. & Paupy, C. (2010) Geographic and ecological distribution of dengue and chikungunya virus vectors, *Aedes aegypti* and *Aedes albopictus*, in urban environments of Cameroon (Central Africa). *Journal of Medical and Veterinary Entomology* **24**, 132–141.

Kow, C.Y., Koon, L.L. & Yin, P.F. (2001) Detection of dengue viruses in field caught male *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) in Singapore by type-specific PCR. *Journal of Medical Entomology* **38**, 475–479.

Kusumawathie, P.H.D., Yapabandara, A.M.G.M., Jayasooriya, G.A.J.S.K. & Walisinghe, C. (2009) Effectiveness of net covers on water storage tanks for the control of dengue vectors in Sri Lanka. *Journal of Vector Borne Disease* **46**, 160–163.

Leroy, E.M., Nkoghe, D., Ollomo, B., Nze-Nkogue, C., Becquart, P., Grard, G., Pourrut, X., Charrel, R., Moureau, G., Ndjoyi-Mbiguino, A. & De-Lamballerie, X. (2009) Concurrent chikungunya and dengue virus infections during simultaneous outbreaks, Gabon, 2007. *Emerging Infectious Disease* **15**, 591–593.

Lounibos, L.P. (2002) Invasions by insect vectors of human disease. *Annual Review of Entomology* **47**, 233–266.

Manimunda, S., Singh, S.S., Sugunan, A.P., Singh, O., Roy, S., Shriram, A.N., Bharadwaj, A.P., Shah, W.A. & Vijayachari, P. (2007) Chikungunya fever, Andaman and Nicobar Islands, India. *Emerging Infectious Disease* **13**, 1259–1260.

Mattingly, P.F. (1957) Genetical aspects of the *Aedes aegypti* problem. Taxonomy and binomics. *Annals of Tropical Medicine and Parasitology* **51**, 392–408.

Medlock, J.M., Hansford, K.M., Schaffner, F., Versteirt, V., Hendrickx, G., Zeller, H. & Van Bortel, W. (2012) A review of the invasive mosquitoes in Europe: ecology, public health risks, and control options. *Vector Borne Zoonotic Disease* **12**, 435–447.

Mitchell, C.J. (1995) Geographic spread of *Aedes albopictus* and potential for involvement in arbovirus cycles in the Mediterranean Basin. *Journal of Vector Ecology* **20**, 44–58.

Nagpal, B.N. & Sharma, V.P. (1983) Mosquitoes of Andaman Islands. *Indian Journal of Malariology* **20**, 7–13.

Ngoagouni, C., Kamgang, B., Nakouné, E., Paupy, C. & Kazanji, M. (2015) Invasion of *Aedes albopictus* (Diptera: Culicidae) into central Africa: what consequences for emerging diseases? *Parasites & Vectors* **8**, 191.

Nicholson, J., Ritchie, S.A. & van den Hurk, A.F. (2014) *Aedes albopictus* (Diptera: Culicidae) as a potential vector of endemic and exotic arboviruses in Australia. *Journal of Medical Entomology* **51**, 661–669.

Pagès, F., Peyrefitte, C.N., Mve, M.T., Jarjaval, F., Brisse, S., Iteman, I., Gravier, P., Tolou, H., Nkoghe, D. & Grandadam, M. (2009) *Aedes albopictus* mosquito: the main vector of the 2007 chikungunya outbreak in Gabon. *PLoS ONE* **4**, e4691.

Paupy, C., Delatte, H., Bagny, L., Corbel, V. & Fontenille, D. (2009) *Aedes albopictus*, an arbovirus vector: from the darkness to the light. *Microbes and Infection* **11**, 1177–1185.

Pistone, T., Ezzedine, K., Schuffenecker, I., Receveur, M.C. & Malvy, D. (2009) An imported case of chikungunya fever from Madagascar: use of the sentinel traveler for detecting emerging arboviral infections in tropical and European countries. *Travel Medicine and Infectious Disease* **7**, 52–54.

Rey, J.R., Nishimura, N., Wagner, B., Braks, M.A., O'Connell, S. M. & Lounibos, L.P. (2006) Habitat segregation of mosquito arbovirus vectors in south Florida. *Journal of Medical Entomology* **43**, 1134–1141.

Savage, H.M., Ezike, V.I., Nwankwo, A.C., Spiegel, R. & Miller, B.R. (1992) First record of breeding populations of *Aedes albopictus* in continental Africa: implications for arboviral transmission. *Journal of the American Mosquito Control Association* **8**, 101–103.

Seneviratne, S.L., Gurugama, P. & Perera, J. (2007) Chikungunya viral infections: an emerging problem. *Journal of Travel Medicine* **14**, 320–325.

Shriram, A.N. & Sehgal, S.C. (1999) *Aedes aegypti* (L) in Port Blair, Andaman and Nicobar Islands-distribution and larval ecology. *Journal of Communicable Diseases* **31**, 185–192.

Shriram, A.N., Sugunan, A.P. & Vijayachari, P. (2008) Infiltration of *Aedes aegypti* into peri-urban areas in South Andaman. *Indian Journal of Medical Research* **127**, 618–620.

Shriram, A.N., Sugunan, A.P., Manimunda, S.P. & Vijayachari, P. (2009) Community-centred approach for the control of *Aedes*Spp in a peri-urban zone in the Andaman and Nicobar Islands using Temephos. *National Medical Journal of India* **22**, 116–120.

Shroyer, D.A. (1986) *Aedes albopictus* and arboviruses, a concise review of the literature. *Journal of the American Mosquito Control Association* **2**, 424–428.

Sivan, A., Shriram, A.N., Sunish, I.P. & Vidhya, P.T. (2015) Host feeding pattern of *Aedes aegypti* and *Aedes albopictus* (Diptera, Culicidae) in heterogeneous landscapes of South Andaman, Andaman and Nicobar Islands, India. *Parasitology Research* **114**, 3539–3546.

Sivan, A., Shriram, A.N., Sugunan, A.P., Anwesh, M., Muruganandam, N., Kartik, C., & Vijayachari, P. (2016) Natural transmission of dengue virus serotype 3 by *Aedes albopictus* (Skuse) during an outbreak in Havelock Island: entomological characteristics. *Acta Tropica* **156**, 122–129.

Simard, F., Nchoutpouen, E., Toto, J.C. & Fontenille, D. (2005) Geographic distribution and breeding site preference of *Aedes albopictus* and *Aedes aegypti* (Diptera: Culicidae) in Cameroon, Central Africa. *Journal of Medical Entomology* **42**, 726–731.

Smith, C.E.G. (1956) The history of dengue in tropical Asia and its probable relationship to the mosquito *Aedes aegypti*. *Journal of Tropical Medicine and Hygiene* **59**, 3–11.

Tsuda, Y. & Takagi, M. (2001) Survival and development of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) larvae under a seasonally changing environment in Nagasaki, Japan. *Environmental Entomology* **30**, 855–860.

Tsuda, Y., Suwonkerd, W., Chawprom, S., Prajakwong, S. & Takagi, M. (2006) Different spatial distribution of *Aedes aegypti* and *Aedes albopictus* along an urban-rural gradient and the relating environmental factors examined in three villages in northern Thailand. *Journal of American Mosquito Control Association* **22**, 222–228.

Vazeille, M., Moutailler, S., Coudrier, D., Rousseaux, C., Khun, H., Huerre, M., Thiria, J., Dehecq, J.S., Fontenille, D., Schuffenecker, I., Despres, P. & Failloux, A.B. (2007) Two chikungunya isolates from the outbreak of La Reunion (Indian Ocean) exhibit different patterns of infection in the mosquito, *Aedes albopictus*. *PLoS ONE* **2**, e1168.

Vijayachari, P., Singh, S.S., Sugunan, A.P., Shriram, A.N., Manimunda, S.P., Bharadwaj, A.P., Singhania, M., Gladius, C. & Bhattacharya, D. (2011) Emergence of dengue in Andaman and Nicobar archipelago: eco-epidemiological perspective. *Indian Journal of Medical Research* **134**, 235–237.

WHO (2011) Comprehensive Guidelines for Prevention and Control of Dengue and Dengue Hemorrhagic Fever. Available online at http://www.searo.who.int/entity/vector_borne_tropical_diseases/documents/SEAROTPS60/en/ (accessed 31 January 2016).

Yoosuf, A.A., Shiham, I., Mohamed, A.J., Ali, G., Luna, J.M., Pandav, R., Gongal, G.N., Nisaluk, A., Jarman, R.G. & Gibbons, R.V. (2009) First report of chikungunya from the Maldives. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **103**, 192–196.