

The spatial distribution of *Aedes aegypti* and *Aedes albopictus* in a transition zone, Rio de Janeiro, Brazil

Padrões da distribuição espacial do *Aedes aegypti* e *Aedes albopictus* em uma zona de transição no Rio de Janeiro, Brasil

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Abstract

Dengue fever has become the most important vector-borne viral disease in Brazil. Human facilitated transport of desiccation-resistant eggs has led to its two most important vectors, Aedes aegypti and Ae. albopictus, becoming widespread. In this paper, we report seasonal and spatial variation in larval abundances of Ae. aegypti and Ae. albopictus across a small-scale transition zone between an urban area and an urban wooded/forested area within Rio de Janeiro, Brazil. We installed 400 ovitraps across 10 sites with different human population densities and vegetation coverage. Eggs and larvae were collected for three weeks during the wet and dry seasons of 2002 and 2003. Ae. albopictus was predominantly found in the forested areas of the study site whereas in the urbanized area Ae. aegypti was more abundant. Both species peaked during the wet season. This distribution pattern, which may reflect adult flight range, may favor the co-occurrence of larvae of these species in a small-scale urban/urban forest transition zone.

Aedes; Dengue; Spatial Analysis

Introduction

The reemergence of dengue fever in Brazil began in 1986, a few years after the recolonization of the country by its main vector *Aedes aegypti*. The other potential dengue vector, *Ae. albopictus*, was discovered in Brazil in 1986. Factors such as human-facilitated transportation of desiccation-resistant eggs have led to *Ae. aegypti* and *Ae. albopictus* becoming widespread. In addition, the Brazilian climate offers favorable conditions for the invasion and expansion of dengue vectors ¹. The spread of dengue vectors is helped by the intensity, frequency and speed at which people and cargo are transported within the country ². A recent study, conducted in Nova Iguaçu in the metropolitan area of Rio, showed that densely populated neighborhoods located close to highways with intense traffic can facilitate the introduction and circulation of dengue viruses ^{3,4}. In these areas, strategic points such as gasoline stations, tire shops and scrap metal yards are strategically important for the surveillance of dengue vectors ³.

Ae. aegypti and *Ae. albopictus* are sympatric species that tend to breed in similar sites, most commonly in artificial containers ^{5,6}. Inter-specific competition between these species has been documented. Early work suggested *Ae. aegypti* to be the superior competitor ⁷. More recent works, however, have shown that *Ae. albopictus* may be superior under laboratory ^{8,9} and

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field conditions^{10,11}, which probably explains displacements of *Ae. aegypti* by *Ae. albopictus* in some areas^{10,12}. In North America and Brazil, the introduction of *Ae. albopictus* has been associated with a decrease in the abundance of *Ae. aegypti*^{13,14}, with an impact on the geographical distribution of this species^{15,16,17}.

Urbanization and vegetation coverage seem to have significant but opposite effects on the occurrences of *Ae. aegypti* and *Ae. albopictus*¹⁸. Studies conducted in the Tijuca Forest in Rio de Janeiro^{19,20}, showed that *Ae. aegypti* and *Ae. albopictus* were more abundant near houses than deeper in the forest¹⁹. The dispersal of *Ae. aegypti* and *Ae. albopictus*, estimated using mark-release-recapture techniques, showed that *Ae. albopictus* can fly between sylvatic and peridomestic environments while *Ae. aegypti* had a lower tendency to disperse into the forest²⁰, suggesting that the urban forest is a refuge for *Ae. albopictus*.

Several authors have shown that *Ae. aegypti* is more prevalent in highly urbanized and densely populated neighborhoods, whereas *Ae. albopictus* is more prevalent in rural, suburban, and forested urban areas^{17,18,19,20,21,22}. However, most of these studies have analyzed the distribution of *Ae. aegypti* and *Ae. albopictus* on a large (city) scale. The goal of the present study was therefore to add further analysis to this process by looking at *Ae. aegypti* and *Ae. albopictus* distribution patterns at a local scale. In this paper, we report seasonal fluctuations in the larval occurrences of *Ae. aegypti* and *Ae. albopictus* across a spatially heterogeneous landscape, characterized by two distinct habitats – a highly populated low income urban area, and a vegetated, more sparsely populated area – separated by a sharp transition zone (the border of the Oswaldo Cruz Foundation – FIOCRUZ – campus), in the city of Rio de Janeiro. By characterizing the seasonal and spatial variation in the larval density of both species, we attempted to address the factors contributing to the competitive advantages for each species.

Material and methods

Study site

The area encompasses the campus of FIOCRUZ, Rio de Janeiro, Brazil (22°52'30"S, 43°14'53"W; 697,000m²), with large vegetation patches, and the surrounding area, which are densely populated by low income residents and known as slums (*comunidades* or *favelas*) (Figure 1). This forested area within the campus is a refuge for a variety of mammals and birds. Ten collecting sites were defined, each representing different levels of an-

thropic modifications, types of urbanization and land use. Table 1 lists the main characteristics of these sites.

The climate in Rio is tropical, with a drier winter (May-September) and a rainy summer (November-March). Air temperature and precipitation data were obtained from the nearest meteorological station, located 10km from the study site.

Classification of land coverage and infestation maps

A visual review of an aerial photograph of the area allowed us to classify the study area into four zones: (1) densely built urban – an area composed mainly of residential and commercial buildings; (2) low vegetation coverage – an area composed of short vegetation, mostly grass; (3) medium vegetation coverage – an area composed of average size vegetation, shrubs or small trees that were spatially scattered; and (4) high vegetation coverage – an area composed mainly of tall vegetation, in patches (Figure 1). Maps showing the spatial distribution of *Ae. aegypti* and *Ae. albopictus* larval density in wet and dry seasons were created using a kernel density estimator (Gaussian function and smooth kernel of 100m radius. ArcGis 9.1, ESRI; <http://www.esri.com/software/arcgis/index.html>). The kernel density estimator that was chosen is an interpolation and smoothing technique for generalizing point location to an entire area and consists of a bi-dimensional function of the events, forming a surface whose value is proportional to the intensity of samples for the area²³.

Entomological survey

Four entomological surveys were carried out during the wet and dry seasons of 2002 and 2003. In each of the ten study sites (Figure 1), we installed 40 ovitraps (a plastic vase with a wooden oviposition paddle and hay infusion as described previously)¹⁶. After seven days, eggs and larvae were collected. This procedure was repeated during three consecutive weeks. Larvae were identified and counted in the laboratory. Paddles were stored at 25-28°C and > 80% humidity and immersed in water after two weeks; hatching larvae were reared up until the fourth instar, and identified using key by Consoli & Lourenço-de-Oliveira²⁴.

Statistical analysis

Analysis of variance (ANOVA) was used for testing seasonal and spatial trends of the log-trans-

Figure 1

The study site was an urban/urban forest in a small-scale transition zone.



Table 1

Main characteristics of the descriptors of each site within and outside of FIOCRUZ campus, Rio de Janeiro, Brazil.

Sites	Distance from the border (m)	Area (m ²)	Exposed human population * (approximate)	Land coverage			
				% urban	% low vegetation	% medium vegetation	% high vegetation
C1 *	52	12,071.63	65 *	21.06	0.00	15.81	63.13
C2 *	109	49,895.80	119 *	7.27	0.00	0.00	85.21
C3 *	66	38,381.01	30 *	16.67	0.00	11.94	71.04
C4 *	340	48,975.61	460 *	20.69	21.97	54.32	3.01
C5 *	254	39,688.21	285 *	17.60	26.96	55.45	0.00
C6 *	88	38,631.98	756 *	19.58	0.85	68.81	0.00
C7 *	10	50,756.49	10 *	27.01	22.64	34.34	0.00
P8 **	-82	18,545.67	3,199 *	73.33	0.00	0.00	12.30
P9 **	-50	19,348.76	1,175 *	82.34	6.49	0.04	0.00
P10 **	-43	25,364.43	4,923 *	89.77	0.00	0.00	0.00

* Exposed population inside forested area (FIOCRUZ Campus) was obtained from the Human Resources Department of FIOCRUZ;

** Data of respected population in slums were obtained from the Instituto Brasileiro de Geografia e Estatística (IBGE).

formed occurrences of immature specimens. Simple Pearson correlations were used to test for associations between species densities. Least squares regression was used for fitting exponential models for infestation vs. distance. The slope of the regression line for each season were compared as described by Zar²⁵.

Results

Specimens

A total of 57,779 immature mosquito specimens were collected, 41% of which were *Ae. aegypti* and 59% *Ae. albopictus*.

Spatial distribution

No significant difference was observed between the log transformed mean number of larvae obtained at the first, second, and third weeks of each collecting period. *Ae. albopictus* was more abundant in areas with high to medium dense vegetation coverage ($F_{1,118} = 78.63$, $p < 0.001$), whereas densely populated areas were dominated by *Ae. aegypti* ($F_{1,118} = 94.82$, $p < 0.001$). The species co-occurred at the transition zone between highly populated and highly vegetated areas (Figures 2 and 3). Figure 4 shows the result of fitting a linear regression line to log (larvae) x distance from the campus border ($r^2 = 0.78$,

$F_{1,6} = 21.74$ [$p < 0.01$] for the wet season and $r^2 = 0.84$, $F_{1,6} = 32.39$ [$p < 0.01$] for the dry season). In the wet season, the regression curve was: [proportion *Ae. aegypti*] = $1.5115(\exp([\text{distance}] - 0.0065))$. From this model, we estimate that 72% of *Ae. aegypti* larvae were within 50m from the border, approximately 50% at 100m, and only 3.8% beyond 500m. For the dry season, the regression curve was: [proportion *Ae. aegypti*] = $1.6793(\exp([\text{distance}] - 0.0056))$, suggesting slightly wider larval distribution. For example, 57% would fly 100m and 6% would fly 500m. The slope of the regression line for each season did not differ significantly (Student's t-test).

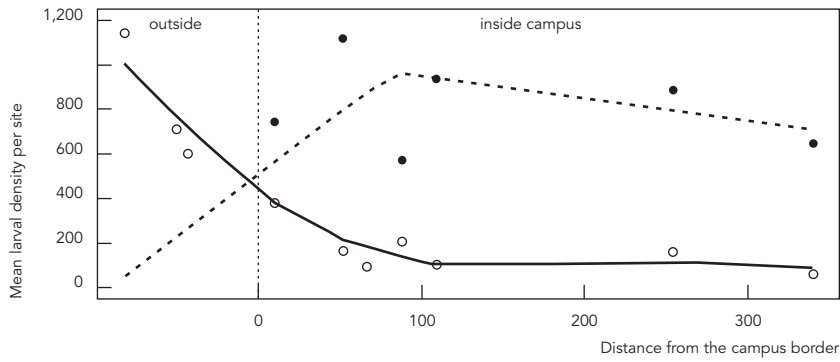
Seasonal variations

Approximately 50% and 28% of all *Ae. albopictus* and *Ae. aegypti* larvae were collected during the wet season and summer, respectively. The percentage of positive ovitraps also varied between seasons. After a period with positive traps typically < 50% during the wet season of 2003, we observed an increase in both *Ae. aegypti* and *Ae. albopictus* frequencies (mean percent of positive ovitrap of ~90%). Seasonal variation in rainfall and temperature is shown in Figure 5. Outside the forest area, both species showed similar temporal patterns, characterized by relatively constant densities during the first year, but with a peak in the wet season of 2003, and a return to the baseline level (Figure 6). Rainfall indices varied

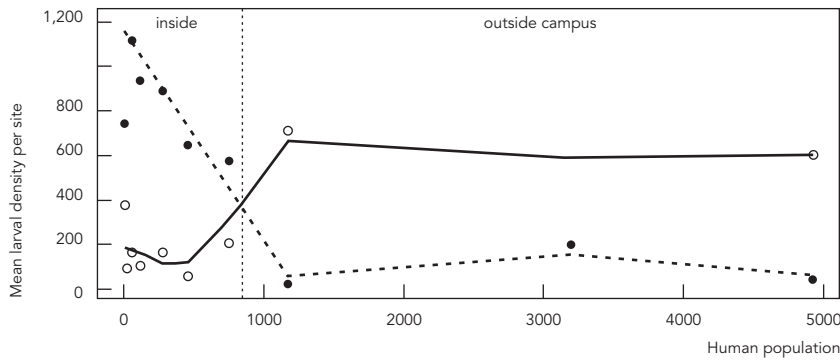
Figure 2

Mean density per site of immatures of *Aedes aegypti* (white cycle) and *Aedes albopictus* (black cycle) as a function of distance from the border of the forest area, human population, and % vegetation coverage.

2a) Distance from the campus border



2b) Human population



2c) % vegetation coverage

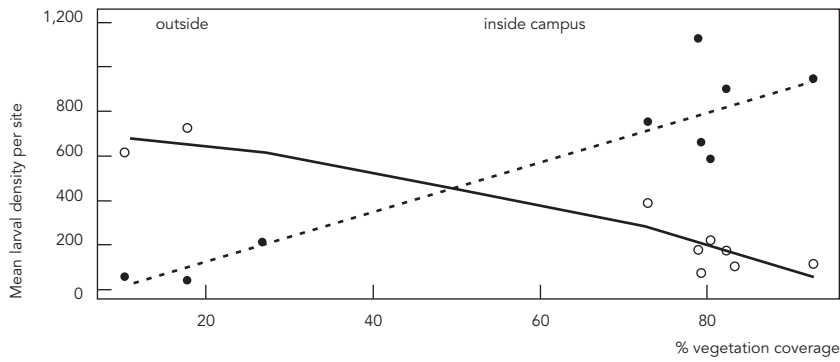
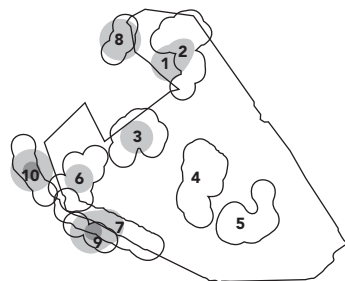


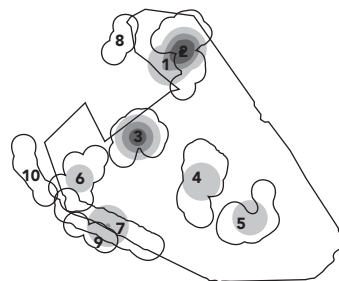
Figure 3

Kernel estimation of density of immatures of *Aedes aegypti* and *Aedes albopictus* inside and outside of forest area during wet and dry seasons, 2002 and 2003. Sizes of the circles indicate abundance of larval density.

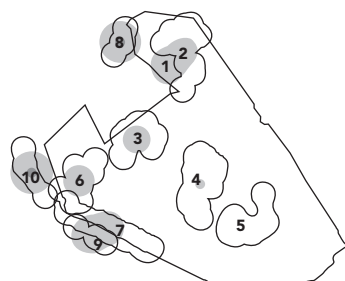
3a) *e. egypti* - wet 2002



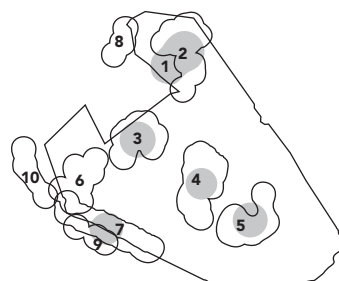
3b) *e. albopictus* - wet 2002



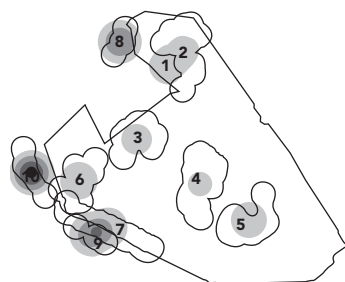
3c) *e. egypti* - dry 2002



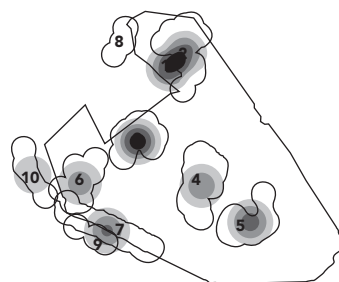
3d) *e. albopictus* - dry 2002



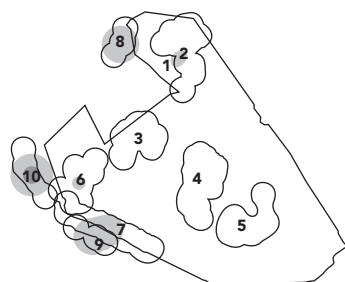
3e) *e. egypti* - wet 2003



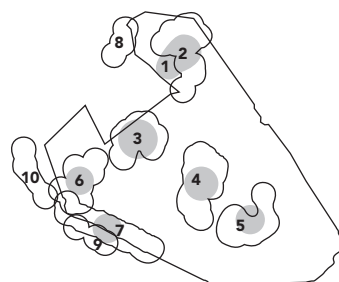
3f) *e. albopictus* - wet 2003



3g) *e. egypti* - dry 2003



3h) *e. albopictus* - dry 2003



Larval density

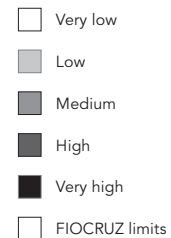


Figure 4

Percentage of *Aedes aegypti* larvae retrieved, as compared to the number obtained in the urbanized area, decreased exponentially with the distance to the wall of the forest area. The lines represent the least squares regression fit of the data for the function $y = b \cdot \exp(x \cdot a)$, during the wet season (circles) and dry season (squares).

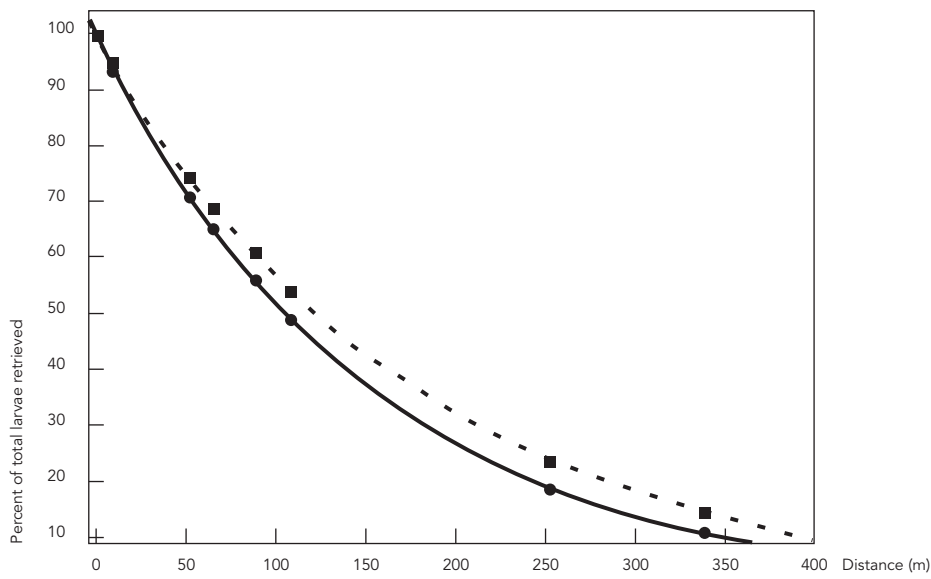
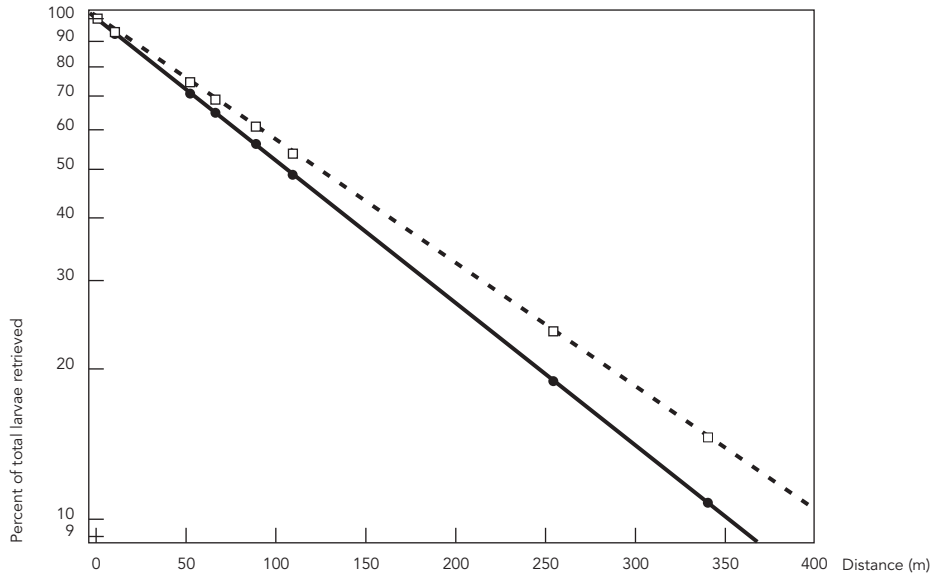
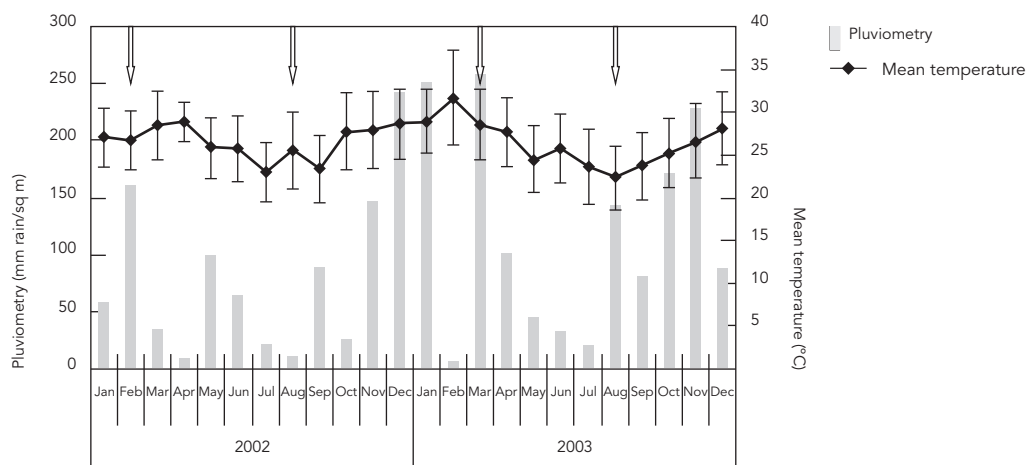


Figure 5

Total rainfall and mean temperature per month, 2002 and 2003. Vertical bars indicate maximum and minimum mean monthly temperature. Arrows indicate periods of data collection.



intra-seasonally depending on the year, particularly for some months of the year. The years 2002 and 2003 showed distinct rainfall regimes: rainfall peaked in February in 2002, and one month later, in 2003; the spring rainfall started later in 2002 (September) than in 2003 (August); and in December, it rained twice as much in 2002 as in 2003. The thermal variation range was bigger in 2003 than 2002 (Figure 5).

In the forested area, *Ae. aegypti* followed the same pattern observed outside the forested area, but always at a lower density than inside (Table 2). Overall, the density of *Ae. albopictus* was twice that of *Ae. aegypti* inside the forested area (Table 3; Figure 6).

Discussion

Our results show *Ae. albopictus* was more abundant in areas with high to medium dense vegetation coverage, whereas the densely populated areas were dominated by *Ae. aegypti*. These results are consistent with distribution patterns of *Ae. aegypti* (in urban areas) and *Ae. albopictus* (in more densely vegetated areas) found in the literature^{17,18,19,20,21,22}. *Ae. albopictus* was found associated with vegetated areas mostly inside the forested area of FIOCRUZ Campus (Figures 1 and 3), where vegetation coverage is highest. Coexistence occurred at the transition zone, defined

as the area that covers the campus wall and its vicinity (Figure 3). Similarly, co-occurrence of the two species has been reported in suburban areas in Rio de Janeiro^{17,22}. We hypothesize that the host-seeking behavior of *Ae. albopictus* may play a role in this distribution. Areas 4 and 5, with low-medium vegetation coverage, in the center of the forest area were systematically less positive to *Ae. albopictus* than other areas. This may be due to low vegetation coverage.

Both species showed seasonal variation in their larval densities. Overall larval densities for both *Ae. aegypti* and *Ae. albopictus* were greater during the wet seasons (Figure 6). Variation was more marked in *Ae. albopictus* (Figures 2, 3, and 6). This is in concordance with previous studies in Rio de Janeiro⁶. In the dry season of 2002, *Ae. albopictus* and *Ae. aegypti* mean densities decreased in the forest area, but remained constant in the densely built urban area. *Ae. aegypti* was more abundant in the wet season of 2003 than it was in the wet season of 2002. The same was true for *Ae. albopictus*. These may have been due to higher rainfall indices in March (Figure 5).

Data suggest that *Ae. aegypti* has a more stable response to climatic variation. The main cause of the shift in distribution of the two species may be due to a greater increase in egg mortality for *Ae. albopictus* under dry conditions, compared to *Ae. aegypti*²⁶. Therefore, dry conditions could shift the competitive advantage away from *Ae.*

Table 2

Mean number of *Aedes aegypti* larvae retrieved at each ovitrap area in the wet and dry seasons, 2002 and 2003.

Sites *	2002				2003			
	Wet	SD	Dry	SD	Wet	SD	Dry	SD
C1	119.00	79.67	144.67	190.00	165.00	41.62	25.00	10.58
C2	57.00	46.51	77.00	35.93	103.00	55.03	35.67	48.43
C3	109.00	70.55	71.67	46.82	92.00	19.97	1.00	1.73
C4	28.00	24.27	37.33	28.75	60.67	30.73	12.00	11.14
C5	25.00	12.00	33.33	22.23	161.67	163.84	24.33	28.04
C6	75.33	58.48	98.67	79.86	207.00	49.49	40.00	38.22
C7	123.00	34.60	135.00	43.49	377.67	237.00	108.33	168.66
P8	435.67	184.91	370.33	99.45	1142.67	519.56	470.67	228.82
P9	362.67	243.66	376.33	240.67	711.33	319.31	174.33	95.10
P10	391.33	177.18	183.00	72.92	602.33	295.63	141.67	87.46

Note: standard deviations (SD) for the three weeks are reported.

* Site codes correspond to those in Figure 1.

Table 3

Mean number of *Aedes albopictus* larvae retrieved at each collecting area in the wet and dry seasons, 2002 and 2003.

Sites *	2002				2003			
	Wet	SD	Dry	SD	Wet	SD	Dry	SD
C1	418.00	266.27	165.67	104.85	1,114.33	402.01	66.00	64.44
C2	1,007.67	689.39	298.33	96.73	934.67	295.05	116.33	31.34
C3	888.67	95.71	138.67	202.23	1,276.67	367.22	253.00	112.28
C4	192.67	23.01	97.33	124.42	647.33	266.04	119.00	41.00
C5	140.33	59.54	127.33	132.67	886.67	423.02	80.00	32.79
C6	72.33	53.16	15.33	10.12	572.67	132.88	75.33	51.83
C7	357.00	94.91	94.00	33.41	741.67	234.51	71.33	44.00
P8	31.33	3.06	10.33	10.12	200.33	177.80	30.00	22.61
P9	5.00	6.24	5.67	9.81	27.33	18.58	10.33	8.96
P10	1.00	1.00	15.33	26.56	44.00	3.46	7.67	10.79

Note: standard deviations (SD) for the three weeks are reported.

* Site codes correspond to those in Figure 1.

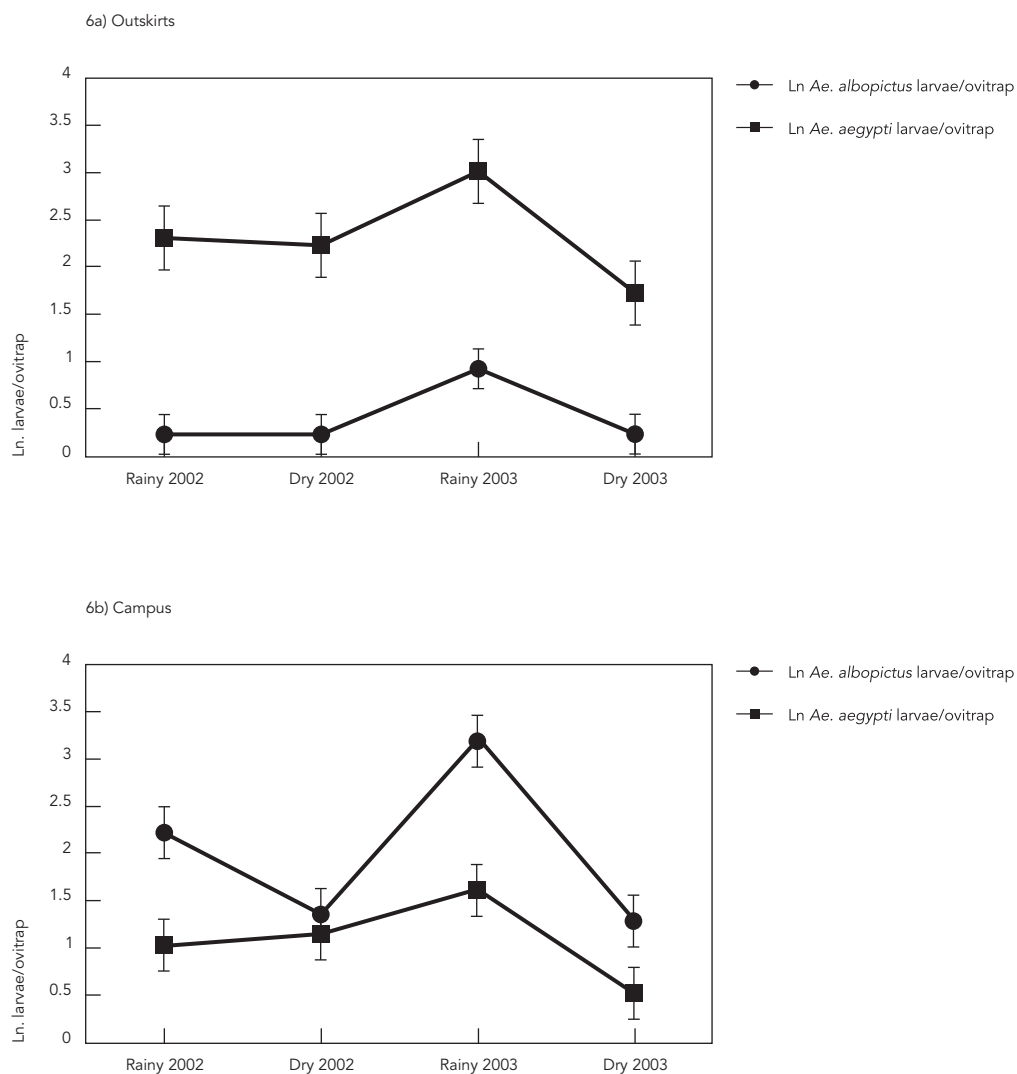
albopictus, favoring *Ae. aegypti*, a pattern documented in controlled laboratory environments²⁷. Nevertheless, the greater stability in *Ae. aegypti* numbers in urban areas could also be due to its habitat preference for domestic situations²². The relatively protected environment provided by housing may favor stable year-long breeding site availability^{20,22}.

Our results suggest that the occurrence of both species varies seasonally and spatially (Figures 2, 3 and 6). *Ae. aegypti* and *Ae. albopictus* were more common in the area closer to the border inside FIOCRUZ Campus and *Ae. albopictus*

was practically absent inside the densely built urban area. Although there was no statistically significant negative correlation for any of the periods separately, the overall densities of both species in the small transition zones were negatively correlated, despite parallel seasonal fluctuations. Because these species colonize distinct habitats in Rio de Janeiro, *Ae. albopictus* may not replace *Ae. aegypti*, and both species may be common in a single area with their abundances positively correlated¹⁷. Also, as suggested in studies in Florida, USA, local coexistence of these species may be possible in a seasonal climate because warm,

Figure 6

Mean number of *Aedes aegypti* and *Aedes albopictus* larvae retrieved in ovitraps in the outskirts of and inside the forest area (campus).



Note: vertical bars denote 95% confidence intervals.

dry climates favor *Ae. aegypti* and reduce the impact of competition from *Ae. albopictus* through differential mortality of *Ae. albopictus* eggs²⁶.

The usual > 1 ratio of *Ae. albopictus* to *Ae. aegypti* larvae was inverted during the dry season of 2002, when *Ae. albopictus* eggs and larvae suffered a decrease in specimen numbers. However, *Ae. aegypti* densities did not increase in collecting sites where *Ae. albopictus* densities remained constant, and this could be a factor related to the distance to the urban area. During the 2003 wet

season, when the percentage of positive ovitraps was high, there was a 50% mean decrease in the expected densities of *Ae. aegypti*, as estimated by the flight range equation. This expected density decrease was most marked in densely vegetated areas, where *Ae. albopictus* was most prevalent.

Due to the low proportion of larvae of *Ae. aegypti* that occurred in natural habitats compared to artificial containers²⁸, we were able to estimate the number of *Ae. aegypti* larvae in the FIOCRUZ campus as a function of the distance

to the urbanized area. The exponential model for *Ae. aegypti* larvae distribution indicates that occurrence of immature forms would be common in the neighboring areas, near the preferred habitat, but would decrease markedly as the distance increased. This distribution pattern, as well as the increased densities of *Ae. albopictus* larvae in the vegetated area, would favor the co-occurrence of larvae of both species.

We have reported seasonal and spatial variations in distribution patterns between *Ae. aegypti* and *Ae. albopictus* within a habitat transition zone. These results suggest that *Ae. aegypti* and *Ae. albopictus* are differentially distributed over hab-

itats and that their numbers may decrease exponentially in relation to the distance traveled^{16,18}. This means that a high rate of both species would be present in a small scale transition zones and inter-specific competition could play a role in these urban/urban-forested transition zones, especially when the number of available breeding sites becomes scarce. Longitudinal studies with more frequent sampling may uncover regular seasonal waves of species invasion and retreat in these areas. Further characterization of transition zones may provide a better insight into the interplay of population dynamics of dengue vectors in small-scale habitats.

Resumo

Dengue tornou-se a mais importante doença viral transmitida por vetores no Brasil. O transporte humano de ovos resistentes à dessecação permitiu que seus dois mais importantes vetores, Aedes aegypti e Ae. albopictus, se tornassem cosmopolitas. Neste artigo, nós avaliamos a variação sazonal e espacial da abundância de larvas de Ae. aegypti e Ae. albopictus por meio de uma pequena escala espacial de zona de transição entre uma área urbana e uma área florestal do Rio de Janeiro, Brasil. Foram instaladas quarenta ovitrampas em cada área dos dez locais caracterizados por diferente densidade populacional humana e cobertura vegetal. Ovos e larvas foram coletados durante três semanas no verão e inverno de 2002 e 2003. Ae. albopictus foi predominantemente encontrado nas áreas com maior cobertura vegetal enquanto que nas áreas urbanizadas (comunidades), Ae. aegypti foi mais abundante. Ambas as espécies apresentaram pico durante a estação chuvosa. Esse padrão de distribuição das formas imaturas pode refletir no raio de vôo do adulto, favorecer a co-ocorrência de larvas dessas espécies nessa pequena escala espacial da zona de transição entre as áreas urbana e de floresta.

Aedes; Dengue; Análise Espacial

Contributors

N. A. Honório participated in the design, planning, data collection, analysis, interpretation, and drafting of the paper. M. G. Castro participated in the design, data collection and data interpretation. F. S. M. Barros collaborated in analysis, data interpretation and drafting of the paper. M. A. F. M. Magalhães helped in the analysis and data interpretation. P. C. Sabroza contributed to the design, analysis, interpretation data, critical review of the content, and approval of the paper's final version.

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