Temporal Distribution of *Aedes aegypti* in Different Districts of Rio De Janeiro, Brazil, Measured by Two Types of Traps

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ABSTRACT Dengue dynamics in Rio de Janeiro, Brazil, as in many dengue-endemic regions of the world, is seasonal, with peaks during the wet– hot months. This temporal pattern is generally attributed to the dynamics of its mosquito vector *Aedes aegypti* (L.). The objectives of this study were to characterize the temporal pattern of *Ae. aegypti* population dynamics in three neighborhoods of Rio de Janeiro and its association with local meteorological variables; and to compare positivity and density indices obtained with ovitraps and MosquiTraps. The three neighborhoods are distinct in vegetation coverage, sanitation, water supply, and urbanization. Mosquito sampling was carried out weekly, from September 2006 to March 2008, a period during which large dengue epidemics occurred in the city. Our results show peaks of oviposition in early summer 2007 and late summer 2008, detected by both traps. The ovitrap provided a more sensitive index than MosquiTrap. The MosquiTrap detection threshold showed high variation among areas, corresponding to a mean egg density of ≈25–52 eggs per ovitrap. Both temperature and rainfall were significantly related to *Ae. aegypti* indices at a short (1 wk) time lag. Our results suggest that mean weekly temperature above 22–24°C is strongly associated with high *Ae. aegypti* abundance and consequently with an increased risk of dengue transmission. Understanding the effects of meteorological variables on *Ae. aegypti* population dynamics will help to target control measures at the times when vector populations are greatest, contributing to the development of climate-based control and surveillance measures for dengue fever in a hyperendemic area.

KEY WORDS population dynamics, *Aedes aegypti*, meteorological variables, dengue, traps

Dengue is the most prevalent mosquito-borne viral disease in the world and an increasingly important cause of morbidity and mortality. Since the reinvasion of Brazil by the primary dengue vector *Aedes aegypti* (L.) in 1977, this country has experienced several dengue epidemics, with 4.5 million cases of dengue until 2008 (Ministério da Saúde 2008). Dengue was first recognized in Brazil in 1981–1982, during an outbreak in the city of Boa Vista, Roraima, northern Brazil. In this outbreak, DENV-1 and DENV-4 serotypes were isolated, and 11,000 cases were confirmed (Osanai et al. 1983). Countrywide transmission of DENV-1 began only 4 yr later, when a large dengue epidemic started in metropolitan Rio de Janeiro. Rio de Janeiro was the port of entry for DENV-2 and DENV-3 into the country, in 1990 and 2001, respectively. In 2001–2002, DENV-3 caused a widespread and severe epidemic with 368,460 cases and 91 deaths (Schatzmayr 2000; Nogueira et al. 2001, 2002). In 2007–2008, during this study, an even more severe epidemic (in terms of case-fatality ratio) occurred (Lourenço-de-Oliveira 2008), with 316,287 cases notified until October 2008, in Rio de Janeiro, and 174 deaths (52 from dengue hemorrhagic fever, 39 cases from dengue shock syndrome, and 83 from other dengue-related complications [SESDEC/RJ 2008]). This latter epidemic, mainly caused by DENV-2, was characterized by a shift toward lower age groups (Teixeira et al. 2008).

Rio de Janeiro is the second largest city of Brazil, with ≈6 million inhabitants (IBGE 2000). Dengue dynamic in Rio de Janeiro, as in many endemic regions of the world, is seasonal, with the highest dengue activity during the late summer (Nogueira et al. 2002, Vezzani and Carbajo 2008, revised by Halstead 2008). Monthly mean temperature and rainfall in Rio de Janeiro (10-yr average) show that the area is characterized by a rainy warm season (November–April), with mean monthly temperatures ranging between 24 and 27°C and rainfall ranging between 100 and 170 mm/mo; and a dry cool season (May–October), with mean temperatures ranging between 21 and 24°C and rainfall between 50 and 100 mm/mo (http://www.

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Table 1. Characteristics of the three study areas based on Census data and surveyed houses

Characteristic	Higienópolis (urban), %	Tubiacanga (suburban), %	Palmares (suburban slum), %	P (χ^2 test)[a]
Access to piped water[b]	99.3	99.1	29.3	<0.001
Only artesian well[b]	0.0	14.0	64.4	<0.001
Sewage service[b]	92.2	46.6	24.2	<0.001
Garbage service[b]	99.3	99.4	97.5	0.89
Poorly maintained households[c]	4.9	25.9	20.0	<0.001
Households with yards (with trees/ cemented)[c]	33.3/56.8	44.5/45.7	52.5/32.5	0.18/0.07
Reporting daily access to water[c]	92.6	85.2	15.0	<0.001
Reporting no piped water[c]	0.0	0.0	45.0	
Yards with potential larval habitats[c]	48.1	54.3	63.8	0.4
Head of family with only basic schooling[c]	34.6	23.5	27.5	0.41
Graduated head of family[c]	25.9	3.7	5.0	<0.001

[a] Chi-square test for differences among areas.

[b] Census data (IBGE 2000).

[c] Surveyed houses (n = 80 per neighborhood).

bdclima.cnpm.embrapa.br/). The seasonal dynamics of dengue transmission has been attributed to the effect of climate on its vector population dynamics. Temperature and rainfall influence many aspects of *Ae. aegypti* life history: temperature affects egg hatch (Gubler 1988; Focks et al. 1993a,b), egg viability (Parker 1986), larval development (Rueda et al. 1990), blood-feeding behavior (Crans et al. 1996), length of the gonotrophic cycle (Pant and Yasuno 1973), female fecundity (Day et al. 1990), adult size (Rueda et al. 1990, Tun-Lin et al. 2000), and adult longevity and dispersal (Hawley 1985, Honório et al. 2003, Maciel-de-Freitas et al. 2007a). Rainfall may affect the abundance and productivity of breeding sites by reducing larval competition and stimulating egg hatching (Moore et al. 1978, Lounibos 1981, Honório et al. 2006, Maciel-de-Freitas et al. 2007b). Low relative humidity has been associated with reduced egg viability, adult survival, and fecundity (Canyon et al. 1999, Costanzo et al. 2006, Luz et al. 2008).

Dengue transmission and vector distribution also show strong spatial heterogeneity. In Rio de Janeiro, higher infestation levels are associated with densely populated neighborhoods, in which unplanned urbanization, irregular sanitation and water supply, and lack of garbage collection foster proliferation of potential breeding sites for *Ae. aegypti*, affecting the abundance of dengue vectors and transmission of the dengue virus (Tauil 2001, Luz et al. 2003).

Mathematical models suggest that variability in mosquito recruitment, together with short-term cross immunity to virus serotypes, are important factors modulating dengue temporal dynamics as well as the coexistence of multiple strains (Bartley et al. 2002, Wearing and Rohani 2006). Thus, spatial and temporal variation in climate, along with spatial variation in human population and conditions in the human environment, should affect conditions for the growth of the primary dengue vector (Wu et al. 2007, Melo et al. 2007) and the transmission of dengue viruses. Despite the importance of climate for the transmission of dengue, few studies have examined detailed longitudinal data sets describing *Ae. aegypti* population dynamics (Scott et al. 2000).

In this study, we present the results of a 1.5-yr continuous survey of *Ae. aegypti* population dynamics, encompassing two hot-wet seasons and one dry-cool season, in three distinct neighborhoods of Rio de Janeiro, by using two types of traps that attract ovipositing females. These neighborhoods differ in income, urbanization, access to water (which influences water storage habits) and garbage collection, presence of yards, vegetation coverage, and history of dengue prevalence. The main objective was to characterize the temporal distribution of *Ae. aegypti* abundance in Rio de Janeiro and its association with local meteorological variables. We hypothesize that temperature should have a similar effect in all three areas, whereas the effect of rainfall should vary according to characteristics of the areas, such as size of outdoor areas and availability of more productive containers.

Materials and Methods

Study Areas. Surveys were performed in three neighborhoods of Rio de Janeiro city: Higienópolis, Tubiacanga, and Palmares, which differ in human population density, sanitation, vegetation cover, and history of dengue (Table 1; Fig. 1). Higienópolis and Tubiacanga are geographically closer (13.1 km apart) than Palmares (30.7 km and 45.1 km from Higienópolis and Tubiacanga, respectively). In March 2007, house index (percent houses infested by *Ae. aegypti*) (Connor and Monroe 1923) was 3.03, 9.83, and 19.48 for Palmares, Higienópolis, and Tubiacanga, respectively. In 2008, Rio de Janeiro city notified 125,988 dengue cases and 100 deaths. In this epidemic, the district of Higienópolis reported 350 dengue cases, whereas 583 were reported in the Galeão area (where the neighborhood of Tubiacanga is located) and 580 in the Vargem Pequena area (where the suburban slum of Palmares is located). The total incidence rates (1: 100,000) were 2110.1, 2695.0 and 4802.4 in Higienópolis, Galeão, and Vargem Pequena, respectively (SMS/RJ 2008).

Higienópolis. Higienópolis (22° 52′25″ S, 43° 15′41″ W) is a neighborhood located within a densely populated urban area in Rio de Janeiro city (human pop-

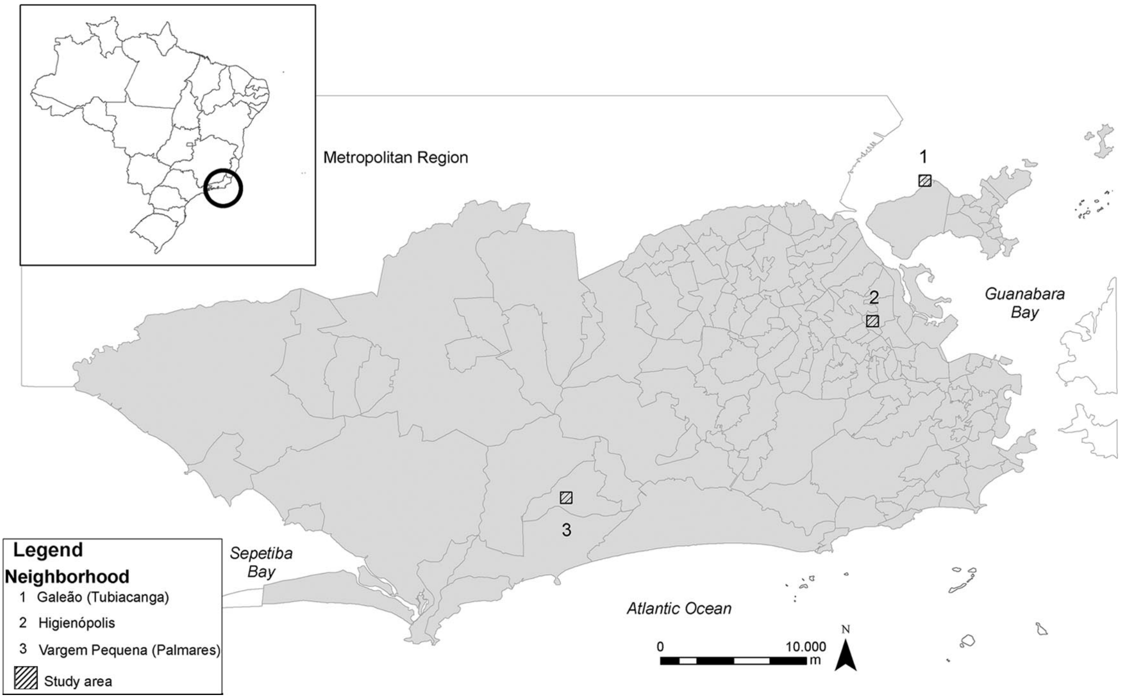

Fig. 1. Map of Rio de Janeiro, Brazil, showing the location of the three studied neighborhoods.

ulation density 15,891 inhabitants per km^2). One of the major city's highways, the Yellow Line, crosses the region. The area is totally urbanized, streets are paved; water supply and garbage services are good. Residents, mostly middle class and aged, live in houses with no or small cemented yards. Vegetation coverage is low. This neighborhood, however, is surrounded by some of the largest slums of Rio de Janeiro, with favorable conditions for *Ae. aegypti* proliferation.

Tubiacanga. Tubiacanga (22° 47′08″ S, 43° 13′36″ W) is a small suburban neighborhood located at the border of the Governador Island, in the Guanabara Bay (human population density 8,219 inhabitants per km^2). This mainly residential neighborhood is mostly occupied by houses with large open yards. Streets are unpaved, garbage collection is regular, but access to water is irregular, and residents often store water in containers, which are potential development sites for immature *Ae. aegypti* (Maciel-de-Freitas et al. 2007a,b).

Palmares. Palmares (22° 59′26″ S, 43° 27′36″ W) is a disordered human settlement started in the 1990s, a suburban slum located in one of the major axes of expansion of the city, to the West. Between the rain forest mountainous range and a polluted river, the human population density in Palmares is 2,732 inhabitants per km^2. Housing distribution is crowded and irregular, with narrow unpaved alleys. Sixty-six percent of the houses investigated reported obtaining water from wells, and water storage in containers is common. Vegetation coverage is low within the neighborhood but very dense around it.

Meteorological Variables. Air temperature was measured at two meteorological stations located <5 km from each of the study areas (the same temperature data were used for Tubiacanga and Higienópolis). Rainfall data for each area were obtained from Prefeitura da Cidade do Rio de Janeiro (GeoRio-http//www.rio.rj.gov.br/georio/alerta/tempo).

Entomological Survey. Two types of traps for ovipositing females were used, ovitraps and MosquiTraps. Ovitraps are black plastic containers, filled with 300 ml of a 10% hay infusion, and a wooden paddle held on the wall for oviposition (Fay and Eliason 1966, Reiter et al. 1991, Honório et al. 2003). The MosquiTrap version 1.0 (Ecovec Ltd., Belo Horizonte, MG, Brazil) consists of a matte black container (16 cm in height by 11 cm in diameter) with ≈280 ml of water and a removable sticky card. A synthetic oviposition attractant, AtrAedes (Ecovec Ltd.), is placed inside the MosquiTrap to attract gravid female mosquitoes (Fávaro et al. 2006). Thus, both traps attract gravid females, but the ovitrap captures the eggs, whereas the MosquiTrap captures the ovipositing female. Using two types of traps for the same population enabled us to generate two simultaneous, independent, time series for each area, which will be used as replicates for validating the estimated meteorological variables effects.

The entomological survey was carried out weekly, from September 2006 to March 2008 during 82 continuous weeks, encompassing two wet-hot seasons and one dry-cool season. In each area, a grid of 500 by 500 m was defined and 80 points randomly selected. The house nearest to each point was selected. Only houses ≥50 m apart were considered. Householders were invited to participate in the study and, upon consent, were interviewed. We recorded information about the house characteristics and the number and education of household members (Table 1). After owner's written consent, traps were placed in these 80 randomly selected houses. One ovitrap was placed in each of 40 houses and one MosquiTrap was placed in each of the other 40 houses. Traps were placed in the peridomestic area, preferably in the garden or in the shade. All traps were inspected weekly during 82 wk. During the inspection, hay infusion in the ovitraps was replaced and wooden paddles collected and individually packed in plastic bags. In the laboratory, positive paddles were stored at 25–28°C and >80% humidity and immersed in water for 1 wk to hatch larvae. Hatched larvae were reared to fourth instar and identified. MosquiTraps, during the inspections, had their sticky cards taken to the laboratory where captured mosquitoes were removed with the aid of probes and forceps, to be identified (Consoli and Lourenço-de-Oliveira 1994 taxonomic keys) and counted under a stereomicroscope. Attractants and sticky cards were usually replaced every 4 wk, but sticky cards were replaced earlier when found to be dusty or dirty. The set of inspected 80 houses in each area remained the same during the whole study (Table 1).

Data Analysis. For the analysis, we calculated two indices: the proportions of positive ovitraps and MosquiTraps per week ("positive" means at least one egg or adult of *Ae. aegypti*) and density indices, calculated as the total number of eggs (or adults) collected in an area, per week, divided by number of traps. To test for differences between areas in total number of *Ae. aegypti* captured, we used chi-square tests.

To infer associations between meteorological variables and mosquito infestation, we fit generalized linear models, using negative binomial distribution and a log link function. The response variable was either the abundance of eggs per week, (D_w), or the abundance of adults per week, (A_w). The explanatory variables were lagged mean air temperature and lagged total precipitation (mm rainfall). An investigation of autocorrelation plots suggested that an auto-regressive term of first order was also necessary.

The full model took the following form:

$$\begin{aligned}\mathrm{Log}[E(Y_w)] &= a_0 + a_1 Y_{w-1} + b_0\,\mathrm{Temp}_w \\ &\quad + b_1\,\mathrm{Temp}_{w-1} + b_2\,\mathrm{Temp}_{w-2} + \dots \\ &\quad + b_n\,\mathrm{Temp}_{w-n} + c_0\,\mathrm{Rain}_w + c_1\,\mathrm{Rain}_{w-1} \\ &\quad + c_2\,\mathrm{Rain}_{w-2} + \dots + c_n\,\mathrm{Rain}_{w-n} + e_t\end{aligned}$$

where $E(Y_w)$ is the expected mosquito abundance (either D_w or A_w), Temp_w is the mean air temperature at week w, and Rain_w is the total amount of rainfall at week w (millimeters). The indices w-1 to w-n stands for the time lags.

Because there is strong correlation between temperature and rainfall measured a few weeks apart, multicolinearity is a problem when fitting such model, which may lead to unstable estimation. To reduce this problem, we opted to use distributed lag modeling (DLM), an approach that has been used in social sciences and pollution epidemiology to estimate lagged effects of climate more efficiently (Souza et al. 2007). In distributed lag models, the variation of the coefficients b_i (i are the lags) is constrained to fit a polynomial function. The motivation behind this approach is the realization that the effect of temperature and rainfall on mosquito density is not instantaneous, but distributes through time in a smooth way.

The same set of nested models was fitted to all three localities: an AR1 model, a model with lagged temperature only, and a model with lagged temperature plus lagged rainfall (we also fitted models with rainfall only, which resulted in poorer fitting compared with temperature only). Akaike's Information Criterion (AIC) was used to assess fitness improvement due to variable addition (Akaike 1974).

To investigate potential nonlinearities on the effects of rainfall and temperature on abundance indices, we also fitted a set of generalized additive models (GAM) with log link function and the negative binomial distribution, to the same outcome variables. GAM is an extension of generalized linear models that allows for the inclusion of nonparametric smoothing terms (Wood 2006) in the place of the constant parameters. By plotting the fitted smooth terms versus the predictor, one may investigate the nature of the relationship between the predictor and the outcome variable, detecting potential nonlinearities.

We started with models with the same structure shown for the DLM analysis, but only keeping the temperature and rainfall lagged terms that proved significant, according to this analysis. Models with and without smoothing terms were compared using AIC (Akaike 1974). Models were fitted in R 2.6.0, using the libraries mgcv and MASS (R Development Core Team 2006). Goodness-of-fit was assessed by AIC, residual plots, autocorrelation function plots, and Spearman's correlation between predicted and observed values.

Results

General Entomological Results. Using ovitraps, 703,649 eggs of *Aedes* species were collected, the majority being *Ae. aegypti* (Table 2) and the remaining being *Aedes albopictus* (Skuse). Approximately half of all eggs were collected in the suburban area (Tubiacanga), one third in the urban area (Higienópolis), and the remaining 18% in the suburban slum (Palmares). Differences in total eggs collected per area were significant ($\chi^2 = 84128$, df = 2, $P < 0.001$) (Table 2).

Using MosquiTraps, 15,059 mosquitoes were captured. Contrasting with the ovitrap, MosquiTraps also attracted non *Aedes* species, mainly *Culex quinquefasciatus* Say. This was especially noticeable in the suburban slum (which is bordered by a polluted river), where ≈85% of all specimens collected were non-*Aedes* species (Table 2). Comparing the three areas, traps in the suburban slum captured *Ae. aegypti* adults the least (only 7% of all captures), whereas traps in the

Table 2. Descriptive statistics of meteorological variables and infestation indices based on 40 MosquiTraps and 40 Ovitraps installed for 82 wk in three study areas in Rio de Janeiro, Brazil

	Higienópolis (urban)	Tubiacanga (suburban)	Palmares (suburban slum)	P (χ^2 test)[a]
MosquiTrap				
Mosquitoes	4,571	5,247	5,241	<0.001
Ae. aegypti	3,977 (87%)	3,854 (73%)	641 (12%)	<0.001
Mean ± SD	1.2 ± 0.4	1.2 ± 0.5	0.2 ± 0.1	
% female *Ae. aegypti*	98	98	96	
Ae. albopictus	40 (0.8%)	173 (3.3%)	131 (2.5%)	<0.001
% female *Ae. albopictus*	95	100	92	
% other mosquitoes	12	24	85	<0.001
% Missing traps	3	1.7	2.7	
Ovitrap				
Number of eggs	252,818 (36%)	323,476 (46%)	127,355 (18%)	<0.001
% *Ae. aegypti*	98	96	91	
Mean ± SD	77 ± 30	101 ± 44	39.7 ± 20	
% *Ae. albopictus*	0.1	0.4	2.2	
% Missing traps	3	1.6	2.9	
Weather				
Rainfall (mm)	1392	1584	1997	<0.001
% Rainy days[b]	34	34.9	35.9	
Mean temp (°C)	24.4[c]	24.4[c]	25.6	

[a] Chi-square test for differences among areas.

[b] Rainy day was any day with rainfall (in millimeters) > 0.

[c] Data obtained at the same meteorological station.

other two neighborhoods shared similar values ($\chi^2 = 0.0034$, df = 1, $P = 0.9533$). Ninety-eight percent of all *Ae. aegypti* collected were females.

Temporal Pattern of Positive Premises. We found very high proportion of positive ovitraps per week in both urban and suburban neighborhoods (Higienópolis and Tubiacanga, respectively), with indices averaging 70–80% year-round and summer peaks reaching 90–100%. In the winter, infestation declined but rarely dropped below 60% (Fig. 2). The suburban slum, however, had lower infestation, with an average of 50% positive premises year round, summer peaks of 70–

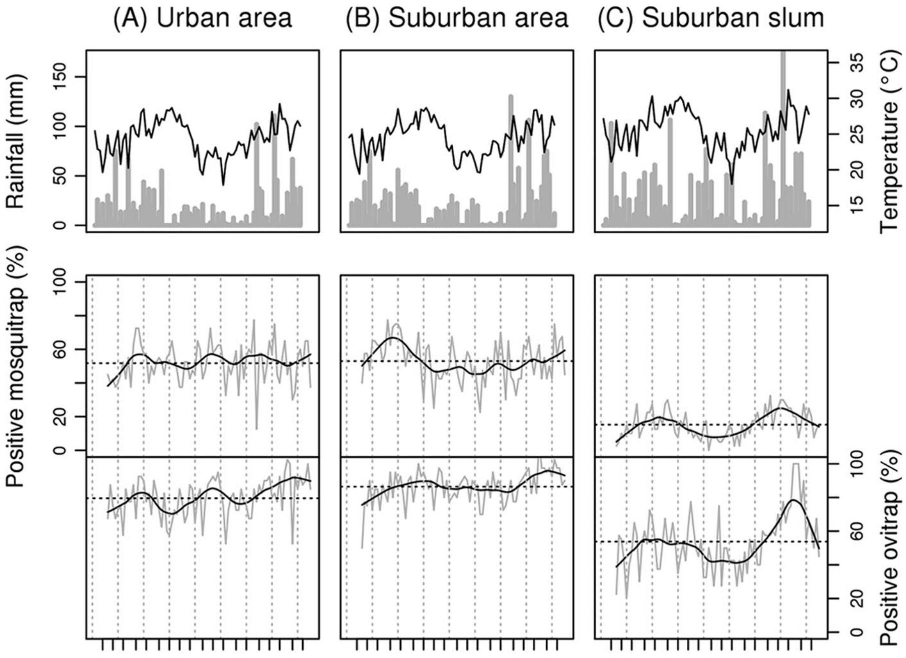

Fig. 2. Time series of mean temperature (Celsius) per week, total rainfall (millimeters), positive MosquiTraps (percentage), and positive ovitraps (percentage), from September 2006 to March 2008, in three neighborhoods of Rio de Janeiro, Brazil: Higienópolis (urban), Tubiacanga (suburban), and Palmares (suburban slum). The solid curve is a natural cubic smoothing spline, and the horizontal line indicates the overall mean trap positivity.

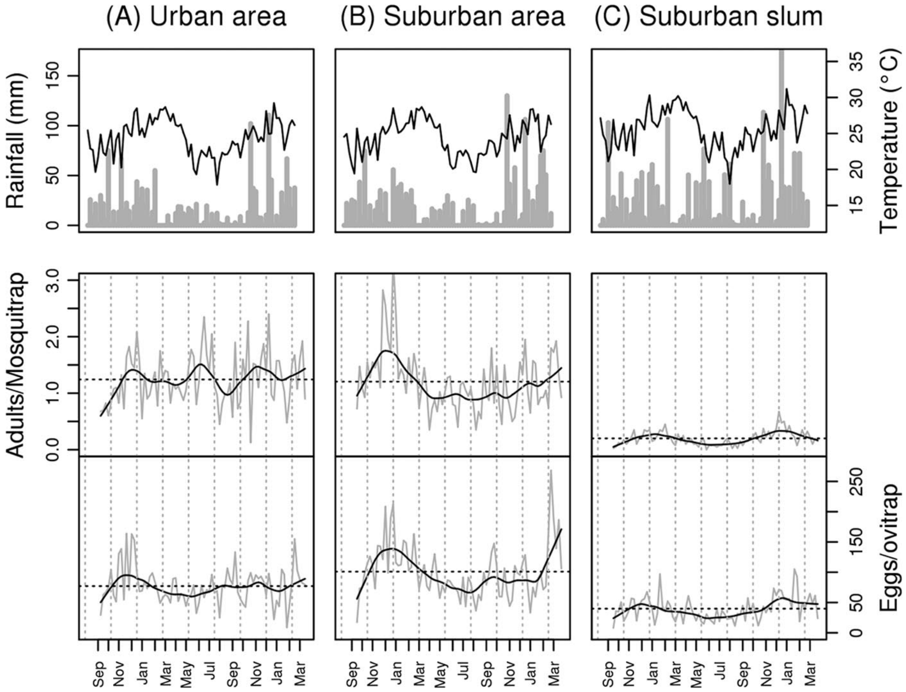

Fig. 3. Time series of mean temperature (Celsius) per week, total rainfall (millimeters), mean adult density per MosquiTraps, and mean egg density per ovitraps from September 2006 to March 2008, in three neighborhoods of Rio de Janeiro, Brazil: Higienópolis (urban), Tubiacanga (suburban), and Palmares (suburban slum).

90%, and winter decline to 20–30%. Time series of all three areas presented oscillations and the second summer had the highest peak.

Using the proportion of positive MosquiTraps to calculate infestation, we obtained lower indices relative to ovitraps. Again, the suburban slum was the least infested, with an average of 15% positivity, summer peaks of ≈30%, and winter declines to 5–10%. The urban and suburban areas shared similar infestation levels (≈50%; summer peaks of ≈70%, and winter declines to 30–40%) (Fig. 2).

Both traps produced the same ranking of areas, though the summer peak was less evident with the MosquiTrap data. Only data from the suburban slum showed the two summer peaks, whereas the suburban area showed only the first peak. There was no suggestion of temporal pattern in the urban area positivity data. (Fig. 2).

Temporal Pattern of Density Indices. Using ovitraps, we calculated the egg density index per week (Fig. 3). With this index, we were able to discriminate between suburban and urban areas, whose values seemed similar when comparing the positivity indices. The suburban area emerges as the most productive area, with a mean of 100 eggs per trap per wk, which doubled during the summer peaks and dropped to half during the winter. The urban area was second most productive, averaging ≈77 eggs per trap per wk, doubling during the summer. The suburban slum was the least productive, with a mean of 39.7 eggs per trap per wk, and summer peaks of 60–70 eggs per trap per wk. The summer peak is evident in suburban and suburban slum and less clear in urban area (no peak in the second summer).

Using MosquiTraps, we calculated the adult density index (Fig. 3). This index did not discriminate between the urban and suburban areas, both with an average of ≈1.3 mosquitoes per trap wk. The suburban slum presented very low indices, averaging only 0.3 mosquitoes per trap per wk. The summer peak is again evident in the suburban area and the suburban slum.

Trap Sensitivity and Comparison Between Indices. Ovitraps were more sensitive than MosquiTraps for detecting *Ae. aegypti* presence as well as measuring infestation intensity. Evidence for this conclusion comes from the higher indices obtained with ovitraps (Fig. 3) and from scatter plots of the total number of eggs versus total number of adults collected per week, in each area (Fig. 4). Fitting linear regressions of the form $D_w = b_0 + b_1 A_w$, we obtained estimates of b_0 (a measure of sensitivity of the ovitraps), and b_1 (a conversion factor adults-eggs) (Table 3). The MosquiTrap detection threshold showed high variation among areas, corresponding to a mean egg density of ≈25–52 eggs per ovitrap, that is, below this amount of eggs, MosquiTraps did not detect the presence of *Ae. aegypti.* For egg density indices above this threshold, each captured adult corresponded to an average of 41.9 ± 9.6 eggs per adult in the suburban area (Tubiacanga), 52.8 ± 9.3 eggs per adult in the urban (Higienópolis), and 24.2 ± 3.6 eggs per adult in the suburban slum (Palmares) (Table 3), indicating high variation in de-

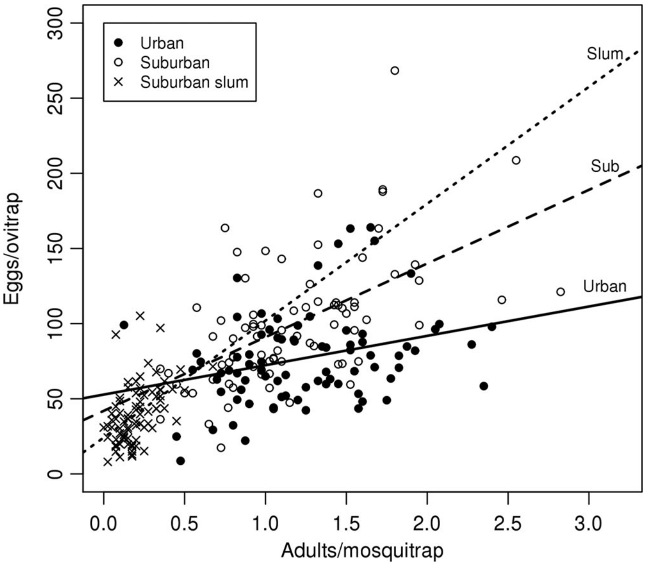

Fig. 4. Scatterplots of number of eggs per ovitrap versus number of adults per MosquiTrap captured per week, in three neighborhoods of Rio de Janeiro, Brazil: Higienópolis (urban), Tubiacanga (suburban), and Palmares (suburban slum). Solid line: linear regression. Dotted line, spline.

tection among areas. These numbers should be considered with caution because differences between detection thresholds may be artificially caused by assuming linearity, and the lack of data on small infestation range in two of the areas.

In two neighborhoods (suburban and suburban slum) the two traps produced moderately correlated density indices (Tubiacanga (suburban): Spearman's $r = 0.60$, $P < 0.001$; Palmares (suburban slum): Spearman's $r = 0.49$, $P < 0.001$). In the remaining area, however, only a weak correlation was observed (Spearman's $r = 0.29$, $P = 0.01$) (Table 3).

Meteorological Variables. The suburban slum, located at the border of the Rio de Janeiro's rain forest mountain range, received the greatest precipitation, with a mean of 98 mm rainfall per mo and well-distributed strong precipitation events throughout the year (Fig. 2). In contrast, the urban and suburban areas, which are located in the rain-shadow of the coastal mountain range, shared lower average precipitation (average of 68–78 mm rainfall per month), with intense events more concentrated in the summer.

Meteorological Variables and Infestation. *Autocorrelation.* We started the regression modeling by inspecting the autocorrelation structure of the egg and adult time series. In two areas (suburban slum and suburban area), both egg and adult time series presented significant autocorrelation, at least at lag 1 (adult series presented longer autocorrelated structure). In contrast, the urban area presented no evidence of autocorrelation. A simple AR model of first order was sufficient to remove the autocorrelation from all series (data not shown).

Lag Distribution of Climate Effects. Figure 5 shows the estimated lag distributed effect of temperature and rainfall on egg and adult mosquito abundance. In all series, the estimated lagged effect of temperature showed a strong positive effect at lag 1. Despite following the same pattern, suburban slum showed less significant effects, possibly because of the lower infestation levels (which reduced the statistical power). Including lag distributed mean temperature in the AR1 model significantly improved the goodness-of-fit in both egg and adult response variables in all three areas (Table 4).

The estimated lagged effect of rainfall was only significant in the suburban area, where at lag 3, both egg and adult time series indicate a significant positive effect. At lag 1, both series suggest a negative effect, but only the egg time series was significant. In the urban area, there is some indication of a positive effect at lags 4 or 5. In the suburban slum, the same is found,

Table 3. Result of fitting the linear model Egg = $b_0 + b_1$ Adult in the three study areas of Rio de Janeiro

	Higienópolis (urban)	Tubiacanga (suburban)	Palmares (suburban slum)
Intercept	52.8 ± 9.3 eggs per adult	41.9 ± 9.6 egg per adult	24.2 ± 3.6 egg per adult
Slope	19.5 ± 7 egg per adult	49 ± 7 egg per adult	77 ± 15 egg per adult
Pearson's *r*	0.29**	0.60***	0.49***

** $P < 0.05$; *** $P < 0.001$.

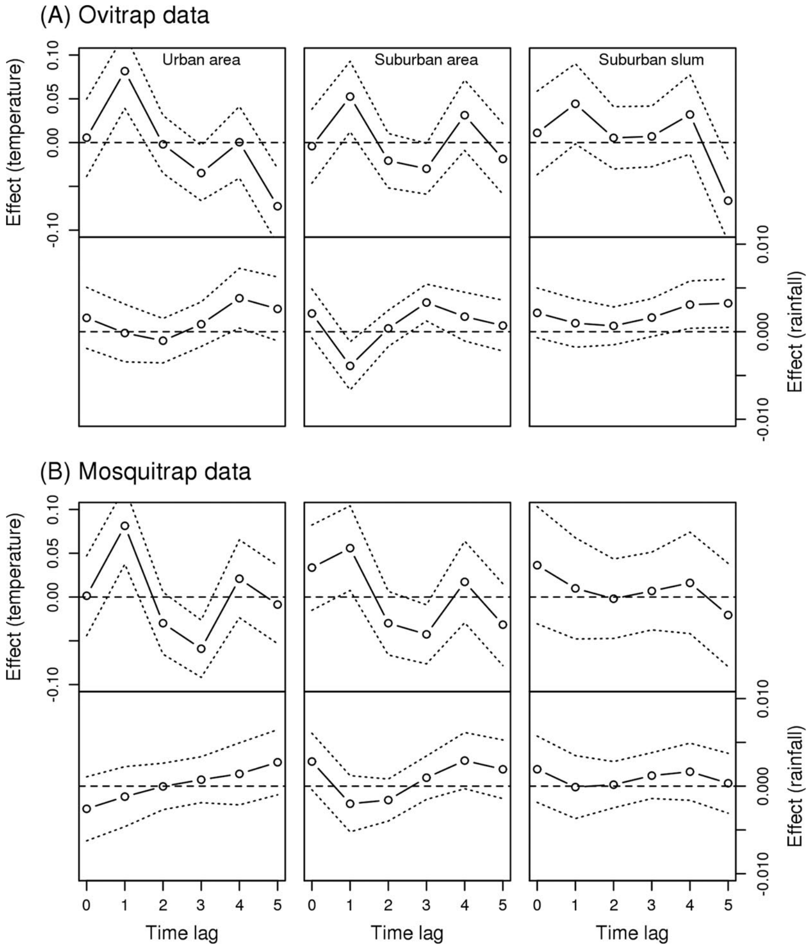

Fig. 5. Lag distributed effect of temperature and rainfall on (A) the mean abundance of eggs, and (B) adults of *Ae. aegypti* in three neighborhoods of Rio de Janeiro, Brazil: Higienópolis (urban), Tubiacanga (suburban), and Palmares (suburban slum). Dotted lines indicated 95% confidence interval.

but only in the egg time series. Only the egg time series models for the suburban and the suburban slum were improved by the inclusion of lagged rainfall in a model with AR1 and temperature.

The effect of temperature at lag one was the only term that consistently presented a nonlinear pattern, the only exception being the adult time series in the urban area (Fig. 6). The pattern obtained suggests that the effect of temperature at lag 1 increases linearly until a threshold (≈22–24°C), above which its effect becomes less significant.

Besides temperature at lag 1, all other effects were adequately represented by fixed terms. The only exception was rainfall at lag 4, in the suburban area, but

Table 4. Comparison of nested DLM models

Response variable	Model	Higienópolis (urban)			Tubiacanga (suburban)			Palmares (suburban slum)		
		r	AIC	p (χ^2)	*r*	AIC	p (χ^2)	*r*	AIC	*P* (χ^2)
Mean egg density	Null		736			776			658	
	AR	0.24	723	<0.001	0.48	738	<0.001	0.36	639	<0.001
	AR + temp	0.48	713	0.001	0.58	736	0.038	0.48	638	0.053
	AR + temp + rainfall	0.57	714	0.123	0.69	733	0.022	0.62	635	0.025
Adult capture rate	Null		665			670			451	
	AR	0.12	657	0.007	0.46	649	<0.001	0.57	415	<0.001
	AR + temp	0.47	651	0.008	0.60	644	0.015	0.59	421	0.58
	AR + temp + rainfall	0.50	655	0.295	0.65	646	0.155	0.59	429	0.82

r, Spearman correlation coefficient; AIC, Akaike information criterion.

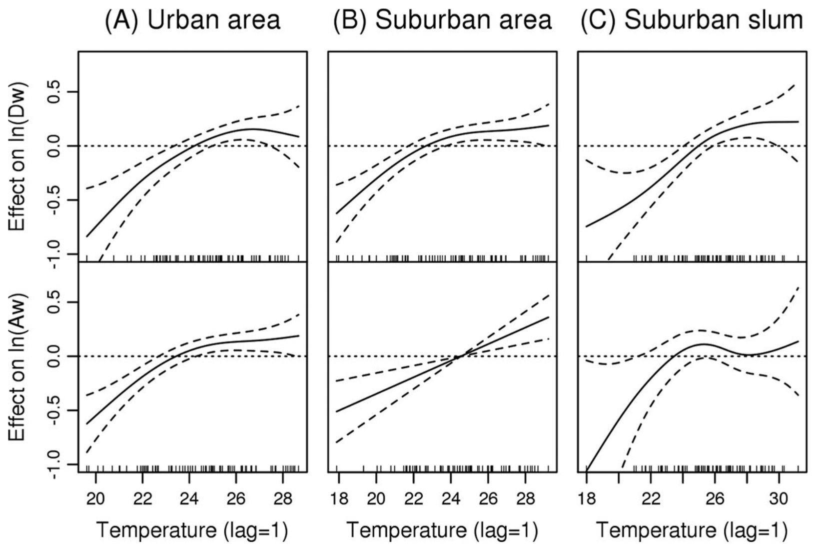

Fig. 6. Smooth effect of temperature at lag 1 wk on the abundance of *Ae. aegypti* adults and eggs: Higienópolis (urban), Tubiacanga (suburban), and Palmares (suburban slum). Dotted lines indicated 95% confidence interval.

the pattern found was inconclusive, as confidence intervals were very large (data not shown). Table 5 presents the results of the best fitted GAM models.

Goodness-of-Fit. The best models (either DLM models or GAM) predicted time series that matched the observed series reasonably well, with Spearman's correlation coefficients ranging ≈0.6 (Tables 4 and 5). Figure 7 presents the time series of fitted and observed egg/adult density. Peaks in the observed data were captured by the models several times, but some of them were also missed badly. There are two peaks in the first summer of the suburban area, which were captured very well in the egg time series, but not in the adult time series. In the urban area, which has a noisier data, most peaks are missed. In the suburban slum, fitting is better for the adult time series. Residual plots show that both DLM and GAM models captured the overall structure of the original data (data not shown).

Discussion

We investigated the temporal dynamics of *Ae. aegypti* abundance indices in three neighborhoods of Rio de Janeiro by using ovitraps and MosquiTraps. Ovitraps are standard tools for *Ae. aegypti* population sampling in many settings, considered a sensitive and cost-effective surveillance apparatus (Fay and Eliason 1966, Braga et al. 2000). They are defended as an

Table 5. Best generalized additive models for egg and adult *Ae. aegypti* density (lag measured in weeks)

Area	Variable	Lag	Effect	SE	*P* value	AIC	*r*
Higienópolis (urban)	Egg	1	0.002	0.001	*	706	0.61
	Temp	1	Smooth		***		
		3	−0.050	0.019	**		
	Rain	4	Smooth		**		
	Adult	1	0.001	0.002	n.s	743	0.43
	Temp	1	0.073	0.019	***		
		3	−0.055	0.019	***		
Tubiacanga (suburban)	Egg	1	0.005	0.100	***	723	0.66
	Temp	1	Smooth		*		
	Rain	1	−0.004	0.001	***		
		3	0.003	0.001	**		
	Adult	1	0.005	0.002	***	638	0.57
	Temp	1	Smooth		***		
		3	−0.04	0.020	*		
Palmares (slum)	Egg	1	0.006	0.002	**	629	0.53
	Temp	1	Smooth		**		
		5	−0.046	0.020	**		
	Rain	4	0.002	0.001	*		
	Adult	1	0.061	0.010	***	410	0.62
	Temp	1	Smooth		*		

Chi-square partial test's *P* value: * $P < 0.1$, ** $P < 0.05$, *** $P < 0.001$.

AIC, Akaike information criterion; *r*, Spearman correlation between observed and fitted values.

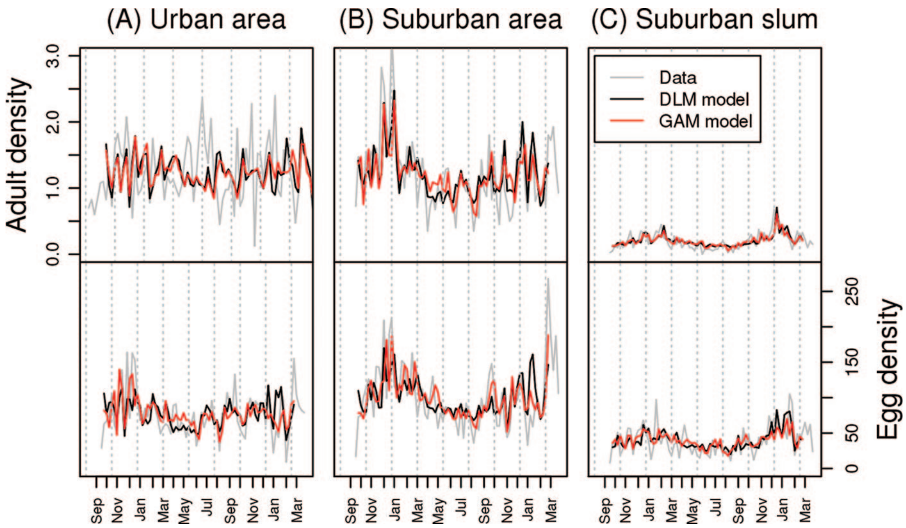

Fig. 7. Time series of *Ae. aegypti* adult and egg captures. In gray, the observed data; in black, the DLM model and in red, the GAM model in three neighborhoods of Rio de Janeiro, Brazil: Higienópolis (urban), Tubiacanga (suburban), and Palmares (suburban slum).

excellent tool to detect the presence of the vector and to compare infestations among different areas (Focks 2003, Vezzani et al. 2004, Morato et al. 2005, Ríos-Velásquez et al. 2007, Regis et al. 2008). However, they are considered poor indicators of transmission risk because their measurement of adult population density is indirect (Focks 2003). Sticky ovitraps such as the MosquiTrap (Eiras 2002, Ritchie et al. 2004, Facchinelli et al. 2007); however, are advocated as a better approach, as they would provide direct measurements of segment of the population (adult females) involved in transmission (Focks 2003, Eiras 2002, Gama et al. 2007, Fávaro et al. 2008).

Despite the main difference (one capturing eggs the other capturing ovipositing females), we proposed that, because both traps target the same population (ovipositing females), their results should be comparable. Our results seem to support this hypothesis. First, both egg and adult time series produced qualitatively similar time series of infestation in the suburban area and suburban slum, with both series showing moderate linear correlation (Fig. 2). In these same localities, both traps also detected the summer peaks and winter declines. The time series obtained for the densely populated urban neighborhood (Higienópolis), however, was noisier and less structured, and the ovitrap and MosquiTrap data showed no correlation. These results may reflect the influence of immigration of gravid females from surrounding sites into the urban neighborhood. In contrast to this urban neighborhood, the suburban slum and the suburban area are both geographically isolated areas (Lourenço-de-Oliveira et al. 2004). When comparing the three areas, both traps also tended to agree, producing the same ranking of infested areas (suburban and urban versus suburban slum). Finally, statistical analysis of the ovitrap and MosquiTrap time series tended to agree on the effect of meteorological variables on *Ae. aegypti* abundance.

Ovitraps showed greater sensitivity than MosquiTraps when used for detecting the presence of mosquitoes in households. Ovitraps always provided higher percentage of positive premises (Fig. 2). Linear regression (Table 4) suggests that the relationship between MosquiTrap and ovitrap captures differ between neighborhoods. The same pattern has been observed by other authors. In Belo Horizonte, Brazil, Gama et al. (2007) observed that ovitraps detected the presence of *Aedes* mosquitoes during 17 wk (egg density varying from 26.6% to 82.0%), whereas the MosquiTrap detected its presence for only 13 wk (with adult density index varying from 0 to 1.6%). Low number of mosquitos captured in the MosquiTrap may be attributable to events of mosquitoes scape from the trap, if they fly away without landing on the sticky card (Gama et al. 2007). A study conducted in Australia with a similar sticky trap, however, showed that sticky traps and ovitraps may detect similar infestation levels (Ritchie et al. 2003). Other potential explanations for the relatively lower efficiency of MosquiTrap compared with ovitrap, may be due to differences in attraction. Fávaro et al. (2006), though, showed that in Mirassol, São Paulo, the sensitivity of MosquiTraps outdoors was 82.1%, whereas that of ovitraps was 89.7%.

By comparing the three areas, we found the suburban and urban neighborhoods considerably more infested than the suburban slum. This is a surprising result, as the suburban slum presents all the conditions for mosquito development (poor housing conditions, poor water supply, and irregular garbage collection). Moreover, contrasting with the other areas, in this suburban slum, the mosquito fauna collected in the traps was dominated by *Cx. quinquefasciatus* (Table

2). This neighborhood is bordered by a polluted river, with high contents of organic matter, a preferred habitat for this species (Consoli and Lourenço-de-Oliveira 1994).

Studies carried out in different parts of the world have found evidence of seasonal pattern of *Ae. aegypti* population density, by using either positivity or quantitative trap indices (Mogi et al. 1988, Micieli and Campos 2003, Vezzani et al. 2004, Stein et al. 2005, Gama et al. 2007, Facchinelli et al. 2007, Vezzani and Carbajo 2008). The strength of the seasonal signal, however, changes with the latitude. In subtropical regions, mosquito abundance tends to be greater during the hot months and very low (or almost absent) during the winter as observed in Buenos Aires, Argentina (Vezzani et al. 2004, Vezzani and Carbajo 2008). In the equatorial region, however, mosquito seasonal variation is more subtle or inexistent, as in the Amazonian city of Manaus (03° 07′ S, 59° 57′ W) (Ríos-Velásquez et al. 2007).

In Rio de Janeiro, a tropical city, we found a significantly positive effect of air temperature at lag 1 wk, on the amount of eggs/adult captured. This effect was found in all three localities for both traps. Temperature at this lag should impact the preadult development of the mosquito population (Schreiber 2001). Below 22–24°C, the effect of temperature was approximately linear and negative, that is, below this threshold, lower temperature contributes to the decline of the mosquito population (Fig. 6). Above 22–24°C, the incremental effect of temperature is not evident. In fact, during yellow fever transmission in 1908, it was verified that *Ae. aegypti* development and reproduction were strongly affected when temperature dropped below 20°C in Rio de Janeiro (Lourenço-de-Oliveira 2008). Moreover, temperatures above 30°C may have minimal impact on *Ae. aegypti* in the field, because this mosquito may avoid excessive daytime heat by resting in cooler, shaded, locations indoors (Schreiber 2001). Previous studies found the maximum survival rates for adult *Ae. aegypti* in the range of 20–30°C (Rueda et al. 1990, Tun-Lin et al. 2000). Beserra et al. (2006) found the favorable temperature for *Ae. aegypti* development is between 21°C and 29°C, and for greater longevity and fecundity, between 22°C and 30°C. Maciel-de-Freitas et al. (2007b) found a tendency toward longer survival of *Ae. aegypti* females during the dry winter (18.3–26.5°C; 44.1 mm rainfall) than in the wet and hot summer (23.3–29.6°C; 1.9 mm) in the suburban area here studied. Our results also suggest a negative effect of temperature at lag 3. This result is less intuitive. A possible explanation for this effect is that temperature also contributes to the reduction of oviposition sites (by evaporation) in areas where discarded containers such as cans, tires, and bottles are important for larvae and pupae maintenance, and such effect may occur at longer lags, when the direct effect of temperature on mosquito biology becomes less important. In addition, previous studies show that long periods of high temperatures and drought may cause high mortality of *Aedes* eggs (Gubler 1988; Costanzo et al. 2006).

In the literature, the effect of rainfall on mosquito dynamics has been elusive (Moore et al. 1978, Lounibos 1981, Scott et al. 2000, Honório and Lourenço-de-Oliveira 2001, Lourenço-de-Oliveira et al. 2004). Rainfall should be important in areas where breeding sites are mainly produced by precipitation. In the urban area (Higienópolis), we observed well maintained yards (clean and cemented) with low potential larval habitats outdoors (Table 1). In the suburban area (Tubiacanga), there is a high availability of permanent containers, such as water tanks and metal drums (not affected by rainfall), as well as a high abundance of containers potentially affected by rainfall (Maciel-de-Freitas et al. 2007b). In the suburban slum, where the main human activity is garbage recycling, there are also many potential breeding sites outdoors. As a consequence, we expected to detect a significant effect of rainfall in the suburban area and the suburban slum, but not in urban neighborhood of Higienópolis.

Our results seem to agree with this expectation. In both suburban neighborhood and suburban slum, the inclusion of rainfall improved the model goodness-of-fit (Table 5), but not in the urban area. When looking at the lag distribution of rainfall effect, though, we find evidence of positive effect of rainfall at longer lags in all three areas, and a short term negative effect (lag 1), only in the suburban. The positive effect of rainfall at lags 3–5 can be attributed to the main impact of rainfall on population dynamics, that is, production of new oviposition sites and egg eclosion stimulation in existing ones. This lag corresponds to the period during which the parent generation was ovipositing the current (captured) generation. Rainfall, at lag 1, however, is likely to affect trap performance and the behavior of the current mosquito generation. In the suburban neighborhood, where most houses are surrounded by open yards, rainfall had a negative effect on trap index at lag 1. Increasing the availability of oviposition sites (generated by precipitation) may reduce the efficiency of the traps, as they have to compete with more alternative oviposition sites. In the urban and the suburban slum, however, where open spaces are rarer, this effect is not observed. This result contrasts with those of Costa-Ribeiro et al. (2006) who suggested that the higher availability of larval habitats during the rainy season would restrain dispersal of *Ae. aegypti* gravid females seeking for sites for oviposition in Higienópolis and Vargem Grande (Palmares neighborhood), leading to low genetic diversity.

In conclusion, the main results of this study can be summarized as follows: qualitative and quantitative indices using ovitraps or MosquiTrap detected similar summer peaks of mosquito population dynamics, suggesting that both could be used for surveillance; however, the ovitrap provided a more sensitive index than MosquiTrap and should be preferable in areas with low infestation (as in the suburban slum). Moreover, the quantitative indices were more sensitive than the qualitative indices when used for comparisons among areas. Rainfall showed a positive effect at long lags (3–5 wk), potentially due to the production of new breeding sites. At last, temperature above 22–24°C was strongly associated with high mosquito density and consequently, an increased risk of dengue transmission. These results are a contribution for the development of a future climate based control and surveillance program for dengue fever in a hyperendemic area.

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