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Dengue outbreaks in Divinopolis, south-eastern Brazil and the geographic and climatic distribution of *Aedes albopictus* and *Aedes aegypti* in 2011–2012

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Abstract

OBJECTIVE To entomologically monitor *Aedes* spp. and correlate the presence of these vectors with the recent epidemic of dengue in Divinopolis, Minas Gerais State, Brazil.
METHODS Ovitraps were installed at 44 points in the city, covering six urban areas, from May 2011 to May 2012. After collection, the eggs were incubated until hatching. In the 4th stage of development, the larvae were classified as *Ae. aegypti* or *Ae. albopictus*.
RESULTS In total, 25 633 *Aedes* spp. eggs were collected. February was the month with the highest incidence, with 5635 eggs collected and a hatching rate of 46.7%. *Ae. aegypti* eggs had the highest hatching rate, at 72.3%, whereas *Ae. albopictus* eggs had 27.7%. Climate and population density influenced the number of eggs found. Indicators of vector presence were positively correlated with the occurrence of dengue cases.
CONCLUSION These data reinforce the need for entomological studies, highlight the relevance of *Ae. albopictus* as a possible disease vector and demonstrate its adaptation. *Ae. albopictus*, most commonly found in forested areas, comprised a substantial proportion of the urban mosquito population.

keywords *Aedes albopictus*, *Aedes aegypti*, dengue, entomological index, ovitraps

Introduction

Mosquitoes of the family *Culicidae* are of great interest to public health because they are important vectors of arboviruses that infect humans (Le Goff *et al.* 2012). Among the known species within this family, *Aedes* (*Stegomyia*) *aegypti* (Linnaeus 1762) and *Aedes* (*Stegomyia*) *albopictus* (Skuse 1894) are prevalent due to their high dispersal ability and adaptation potential. *Ae. aegypti* and *Ae. albopictus* are widely distributed in tropical and subtropical regions (Kobayashi *et al.* 2002) and can be found in urban, suburban and rural areas (Braks *et al.* 2003; Lambrechts *et al.* 2010). The spread of *Ae. aegypti* and *Ae. albopictus* is directly related to domestic or peridomestic conditions offered by human populations (Braks *et al.* 2003; Benedict *et al.* 2007; Tolle 2009). *Ae. aegypti* and *Ae. albopictus* have progressively adapted to anthropogenic changes to the environment. These changes have provided alternative blood sources (domestic animals and human beings) and have produced accumulations of water that serve as larval habitats (Paupy *et al.* 2009). These species have different preferences for egg laying. *Ae. aegypti* prefers artificial receptacles containing fresh water in the form of standing water and with little organic material: tires, cans, potted plants, boxes containing water, and uncapped barrels and cisterns. *Ae. albopictus* can use the same receptacles as *Ae. aegypti*, but it prefers natural receptacles such as hollow trees, fruit peels and bamboo internodes (Consoli & Lourenço-de-Oliveira 1994; Braga & Valle 2007).

The incidence of *Aedes* spp. is related to climatic factors that influence their abundance and distribution. Under favourable climatic conditions, the mosquitoes show greater longevity, enabling the females to increase their blood feeding and egg laying (Padmanabha *et al.* 2012). Precipitation may also influence the abundance and distribution of both *Ae. aegypti* and *Ae. albopictus* because the accumulation of water at domestic and peridomestic sites can increase the number of artificial and natural breeding sites for mosquitoes (Chen & Hsieh 2012).

Aedes aegypti is the principal vector of important arboviruses such as Yellow fever virus, Chikungunya virus, Zika virus, La Crosse virus and the four serotypes of Dengue virus (DENV1-4) (Simard *et al.* 2005; Paupy *et al.* 2009; Rezza 2012). Laboratory studies have demonstrated the competence of *Ae. albopictus* to become infected with and to transmit approximately 26 arboviruses, including Japanese encephalitis virus, West Nile virus, Yellow fever virus and Chikungunya virus (Gratz 2004; Ponce *et al.* 2004). DENV is frequently isolated from wild-caught mosquitoes, also in Brazil. This demonstrates the natural vertical transmission of DENV in *Ae. albopictus*. However, there is no evidence that *Ae. albopictus* is a important urban DENV vector. It has been suggested that *Ae. albopictus* may play a role as a maintenance vector or bridge vector for DENV (Figueiredo *et al.* 2010; Martins *et al.* 2012). However, the occurrence of dengue outbreaks in several countries (parts of China, Seychelles, Japan and Hawaii) where *Ae. aegypti* is absent suggests the hypothesis that *Ae. albopictus* may be a primary vector for DENV (Gratz 2004).

Dengue epidemics have been known in Brazil since 1846. The first reports, dating from 1916 and 1923, described outbreaks in the cities of São Paulo (São Paulo State) and Niteroi (Rio de Janeiro State), respectively (Pedro 1923; Barreto & Teixeira 2008). The first initiative to fight *Ae. aegypti* in Brazil occurred at the beginning of the 20th century (Dick *et al.* 2012). In 1947, the Pan American Health Organization (PAHO) approved an *Ae. aegypti* eradication plan to control urban yellow fever. This plan included Brazil (PAHO 1947). However, the deterioration of control programmes in the 1960s led to the reintroduction of *Ae. aegypti* in Brazil, and dengue outbreaks have been reported in the country since 1981 (Schatzmayr *et al.* 1986). The vector has become widespread in Brazil, and all four DENV serotypes now circulate in the country (Nogueira *et al.* 1991, 2001; Camara *et al.* 2007). Brazil has the largest number of dengue cases in the Americas, and the south-east region has the largest number of cases in Brazil (San Martin *et al.* 2010). Thus several urban centres have adopted strategies to combat dengue (Alencar *et al.* 2008). The only strategy for reducing the number of dengue cases is to eliminate the vector mosquito (Decker 2012). In 1996, another programme was launched by Brazilian researchers in collaboration with PAHO, but it was not sufficient to control the DENV vector. In 2002, a new programme, called *Levantamento Rápido do Índice de Infestação por Ae. aegypti* (LIRAa) by the Index Infestation Premise (IIP), was developed by the Brazilian Ministry of Health through the Dengue Control Program. This new programme is able to provide real-time data to structure specific actions to decrease the prevalence of the vector (Ministério da Saúde: FUNASA – Fundação Nacional de Saúde 2001; Coelho *et al.* 2008).

Divinopolis is the central municipality of the Midwest region of Minas Gerais State, south-east Brazil, and has experienced a considerable increase in the number of dengue cases since the first outbreak in 1998. In 2010, the city had one of the most severe epidemics yet reported, with 5035 dengue cases recorded. In addition, there have been reports of yellow fever virus in this region. A decade ago, an outbreak of yellow fever occurred in the Divinopolis macroregion and resulted in nine deaths (SEMUSA 2001).

In 2010, during a dengue outbreak in Divinopolis, data from LIRAa showed that the average rate of IIP in certain areas ranged from 4.6% to 5.4%, mandating an alert because, according to the Ministry of Health, the desirable IIP is 0.5% to 1%. During the outbreak, 91% of the properties surveyed showed favourable conditions for the proliferation of mosquito larvae (SEMUSA 2010).

We conducted an entomological surveillance study after an epidemic of DENV occurred in Divinopolis in 2010. Our study established a correlation between the incidence of *Aedes* spp. and climatic, socio-economic and demographic measures as well as confirmed dengue cases. Our entomological survey in Divinopolis is unprecedented (in the region) and may contribute to efforts aimed at controlling and monitoring the spread of DENV and other pathogens in this area.

Collection area

Divinopolis is located in the south-east region of Brazil; it has an area of 708 115 km^2, a population of 226 345 and a Municipal Human Development Index of 0.764. According to the Institute of Geography and Statistics (IBGE), the vegetation cover of the area is predominantly savannah (IBGE 2010).

Ovitraps (Fay & Perry 1965) were installed at 44 different locations in an urban residential area in Divinopolis from May 2011 to May 2012. The ovitraps installed were installed in six regions of the city, the central, north-east, west, north-west, south-east and south-west, and they were georeferenced with a Global Positioning System (GPS) (Garmin Dakota 10 & 20 Series, Garmin International, Inc. 1200 East 151st Street, Olathe, Kansas 66062, EE. UU.) (Figure 1). The locations were defined based on the proportional distribution of space between the regions in accordance with the size of each region. Traps were separated by a distance of 250 m, and six to nine traps were distributed in each region, covering the urban areas of the city.

Each point received three ovitraps in different locations. Each ovitrap contained three vanes and was supplied with 500 ml of grassy infusion (*Panicus maximum*) (Reiter *et al.* 1991) for 1 week each month. The ovitraps were installed outdoors in a shaded area on the floor or hung at a height of more than 1.5 m.

Identification of immature stages of *Aedes* spp.

Pallets were deposited in plastic vessels containing water and were covered with a piece of tulle. After 3 days, fish meal (Gold Fish, Colours Bits Alcon) was added to each plastic vessel, and vessels were maintained for 6 days in a biochemical oxygen demand incubator at 26 °C. Larvae in the L3 and L4 stages were identified (Consoli & Lourenço-de-Oliveira 1994).

Data on the average temperature and rainfall in Divinopolis from May 2011 to May 2012 were obtained from the National Institute of Meteorology (INMET) (INMET 2012).

Eggs deposited in each pallet from ovitraps sampled in different areas were counted. The number of eggs counted in the vanes was used to calculate the rate of infestation according to the ovitrap positivity index (OPI), the egg density index (EDI) and the median number of eggs (MNE) per ovitrap, indicating the periods and the regions of higher and lower levels of female reproduction (Gomes 1998; Nunes *et al.* 2011).

Dengue cases

Information on the dengue cases was obtained from the Secretaria Municipal de Saude de Divinópolis/MG (SEMUSA) and Brazil's Health Ministry – System for the Reporting of Notifiable Conditions (SINAN) (SINAN 2014). In addition, the population density in each region of the city and socio-economic data were obtained from the Brazilian IBGE (IBGE 2010).

Data analysis

Variables such as the average monthly temperature and precipitation were compared with the number of eggs collected in each month, using a linear regression. These relationships were evaluated with a Pearson correlation test using Stata software (Stata 8.0, USA). The level of

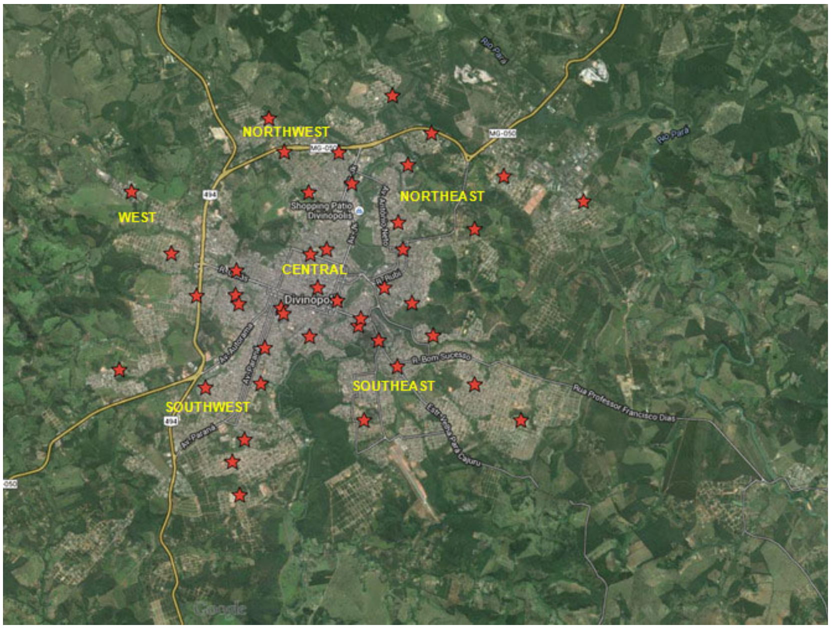

Figure 1 Georeferenced points (red) cover the six regions of Divinopolis/MG (central, south-east, south-west, north-west, north-east and west) as defined by the second division of the county into census areas (IBGE 2010).

significance was set at 5%. OPI, EDI and MNE were also evaluated for the presence/absence of a correlation between socio-economic indicators (average income per household, population density) of the six regions under study. The linear trend of the OPI by region was evaluated with the south-east as the standard for reference.

Results

Number of eggs per site and entomological date

During the collection period, 1716 traps were installed, and 25 633 eggs were collected in the six regions studied (Table 1). The number of eggs collected varied from 9 to 5635, and the mean was 1972. We collected the largest numbers of eggs in December 2011 and February 2012. In July 2011, we only obtained 9 eggs (Table 1). The Central (5635) and West (5303) regions yielded the largest number of eggs. In contrast, the south-west region yielded the small number of eggs (1288) and the lowest MNE per ovitrap (4.13) throughout the study period. The IPO analysis for linear trend in proportions showed a difference between regions, with odds ratios ranging from 1.84 to 5.42 ($P < 0.001$) (Table 1). The entomological indicators (OPI, EDI and MNE) analysed in each region showed that the presence of the vector varied by region, with the lowest value in the south-west (Table 1). The values of the entomological indicators were higher from December 2011 to February 2012, and the lowest values occurred in July 2011 (Table 2). We also compared the entomological indicators with the number of dengue cases by month and with the cumulative number of cases during the years 2007–2012. We observed a decrease in the values of all entomological indicators and

Table 1 Entomological indicators (OPI, EDI, MNE) and number of eggs of *Aedes* spp. collected in ovitraps in various regions of Divinopolis/MG

Region	Number of eggs	Inspected	Positive	OPI (%)	EDI	MNE	OPI: OR for Linear trend in proportions*
Central	5635	273	222	81.32	25.38	20.64	5.01
North-west	4595	273	168	61.54	27.35	16.83	1.84
North-east	5042	351	256	72.93	19.70	14.36	3.10
South-east	3770	234	193	82.48	19.53	16.11	5.42
South-west	1288	312	145	46.47	8.88	4.13	1.00
West	5303	273	206	75.46	25.74	19.42	3.54
TOTAL	25 633	1716	1190	69.35	21.54	14.94	–

*Chi-square for linear trend: 112.905 *P* value < 0.000001.
EDI, egg density index; OPI, Ovitrap positivity index; MNE, median number of eggs.

Table 2 Mean number and total number of eggs, EDI, OPI, MNE and dengue cases by month during study period and cumulatively by month, 2007–2013

Month/2011–2012	Mean of eggs	Number of eggs	EDI	OPI (%)	MNE	Month Dengue cases/2011–2012	Dengue cases/cumulative 2007–2013
May	187.2	1123	38.7	65.9	25.5	10	1768
Jun	170.8	1025	36.6	63.6	23.3	3	389
Jul	1.5	9	1.3	15.9	0.2	2	46
Aug	83	498	25.9	38.6	10	1	15
Sept	83.8	503	27.4	38.6	10.6	0	3
Oct	154.8	929	37.8	38.6	14.6	1	13
Nov	215.7	1294	56.1	52.3	29.3	0	9
Dec	644.2	3865	113.7	77.3	87.8	3	54
Jan	488.2	2929	94.5	70.5	66.6	6	329
Feb	939.2	5635	113.3	90.9	103	4	909
Mar	531.2	3187	88.4	81.8	72.4	1	3682
Apr	496.7	2980	78.4	86.4	67.7	4	3788
May	276	1656	69	54.6	37.6	4	1768
Total	4272.2	25 633	21.5	69.4	14.9	39	11 005

in the number of dengue cases in July. In the subsequent 9 months, the entomological indicators increased and the number of dengue cases followed the same trend (Table 2).

Influence of climatic conditions

The correlations between the number of eggs of *Aedes* spp. and the temperature in the same period and between the occurrence of rain in the week of installation of the ovitraps and the number of eggs in the traps are shown in Figure 2a. The same correlation was also observed in the hatching data for both species (Figure 2b). Figure 3a and b shows that a polynomial fit is preferable for both climatic variables.

Collected eggs *vs.* data provided by IBGE and SEMUSA

As shown in Table 3, there were few correlations between the dengue Incidence Coefficient (IC) per region, for both the study period or the past 7 years, with the average household income ($R = 0.13$ and $R = 0.17$).

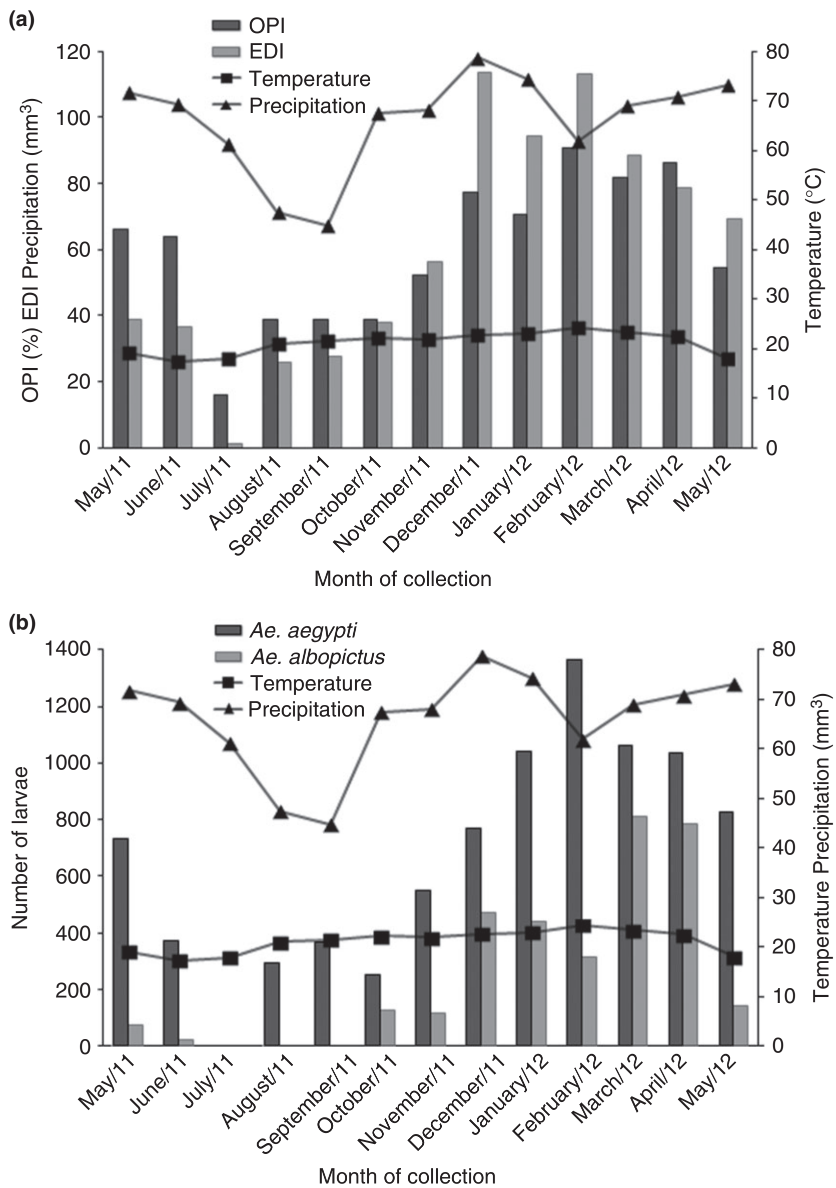

Figure 2 Values of climatic conditions compared with entomological indices, egg density index (EDI) and ovitrap positivity index (OPI) from May 2011 to May 2012 (a). Number of larvae of *Ae. aegypti* and *Ae. albopictus* collected in comparison with the average temperature and precipitation (b).

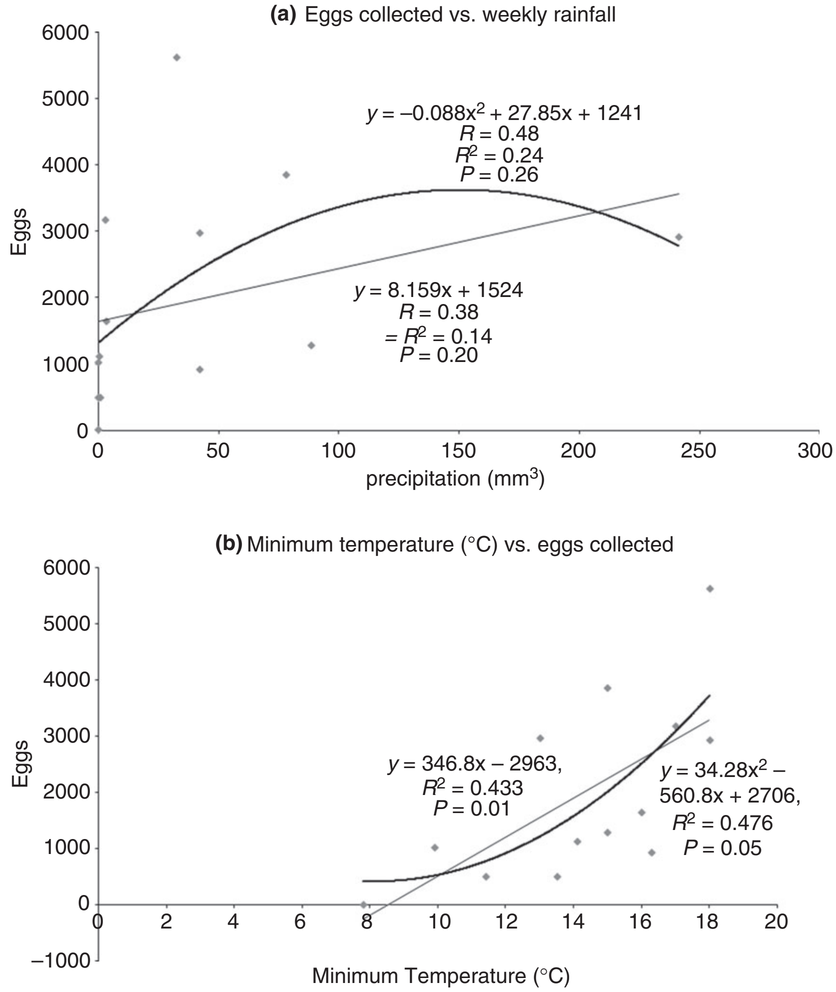

Figure 3 Linear and polynomial regression, weekly precipitation (rain) in mm^3 (a) and minimum temperatures (b) in relation to the total number of eggs in the same period.

These two correlations were not statistically significant (P = 0.81 and P = 0.74, respectively). A low correlation was also observed between the IC of dengue cases per region, for both the study period and the past 7 years, with the population density (R = 0.08, P = 0.87). Likewise, a low correlation was observed between the IC of dengue cases per region, for both the study period and the past 7 years, compared with the coefficient of cumulative incidence between 2007 and 2013 (R = 0.55, P = 0.26). The average number of eggs by traps (MNE) per region was poorly and not statistically significantly correlated with the IC for the study period (R = 0.42, P = 0.40). However, the MNE was strongly and statistically significantly correlated with the 2007–2013 IC (R = 0.81, P = 0.05).

The geographic thematic map showing the demographic density of the census tracts and the pattern of eggs collected during the study period illustrate the concentration of the highest number of eggs in the most densely populated areas. The largest number of eggs during the study period occurred in the Central region (Figure 4).

Larval hatching rate and *Ae. aegypti* or *Ae. albopictus* identification

During the 13 months of data collection, 25 645 eggs were counted, and 46.7% of the larvae hatched, for a total of 11 976. Of these, 8668 were identified as *Ae. aegypti* (72.4% (71.6–73.2%)) and 3308 as *Ae. albopictus* (27.6% (26.8–28.4%)). *Ae. aegypti* hatched in greater numbers from the eggs collected during all months. The south-west, south-east, north-west and west regions had the highest percentages of *Ae. albopictus*. However, during 3 months (Jul 2011–Sep 2011), *Ae. albopictus* was not detected in the eggs that hatched (Figure 5).

Table 3 Mean and standard deviation of socio-economic indicators (values of average income and demographic density); mean by traps of eggs collected, correlated with the Incidence Coefficient of dengue cases in the same period of egg collection and Incidence Coefficient of dengue cases in the past 7 years, Divinopolis regions

Region	Average income per residence*	Demographic density*	MNE	IC Study period†	IC 2007–2013‡
Central	3566.94 ± 2262.2	10 361.53 ± 4865.2	20.64	80.89	6390.21
North-east	1705.6 ± 278.8	4515.1 ± 2946.57	14.36	44.37	5269.39
North-west	2265.15 ± 510.24	3736.93 ± 2242.05	16.83	82.40	4556.82
South-east	1431 ± 231.85	4903.3 ± 1930.74	16.11	91.77	6128.56
South-west	1811.5 ± 307.5	4116.16 ± 3264.91	4.13	60.86	3801.48
West	1820 ± 420.9	5751.67 ± 2637.64	19.42	290.09	7225.09
Study period	$R = 0.13$	$R = 0.08$	$R = 0.42$		
Pearson's correlation	$P = 0.81$	$P = 0.87$	$P = 0.40$		
2007–2013	$R = 0.17$	$R = 0.55$	$R = 0.81$		
Pearson's correlation	$P = 0.74$	$P = 0.26$	$P = 0.05$		

*Information provided by IBGE.
†Information provided by SEMUSA.
‡Information provided by SINAN.

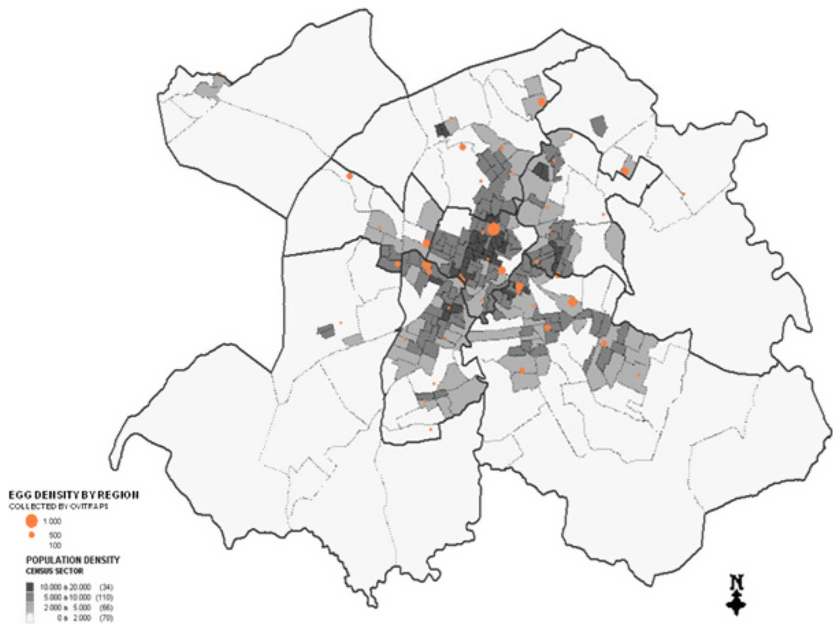

Figure 4 Population density (hab/km²) per census tract in the urban region of Divinopolis and egg density at points with ovitraps.

The most *Ae. aegypti* larvae were found in the Central region, and the fewest in the south-west region. *Ae. albopictus* larvae were more abundant in the north-west, south-east and west regions (Figure 6).

Discussion

Our results show that eggs of *Aedes* spp. are present in almost all regions of the county year-round, demonstrating widespread distribution of *Aedes* spp. in the city. This broad distribution could explain the occurrence of dengue cases throughout Divinopolis.

The results for the entomological indicators (OPI, EDI and MNE) imply that the Central and West regions have a larger infestation of *Aedes* spp. than the other regions of the county. This finding could be related to the increased urbanisation and population density in these areas, which favour the reproduction of the dengue vector due to the existence of numerous artificial breeding pools and the ease of blood feeding

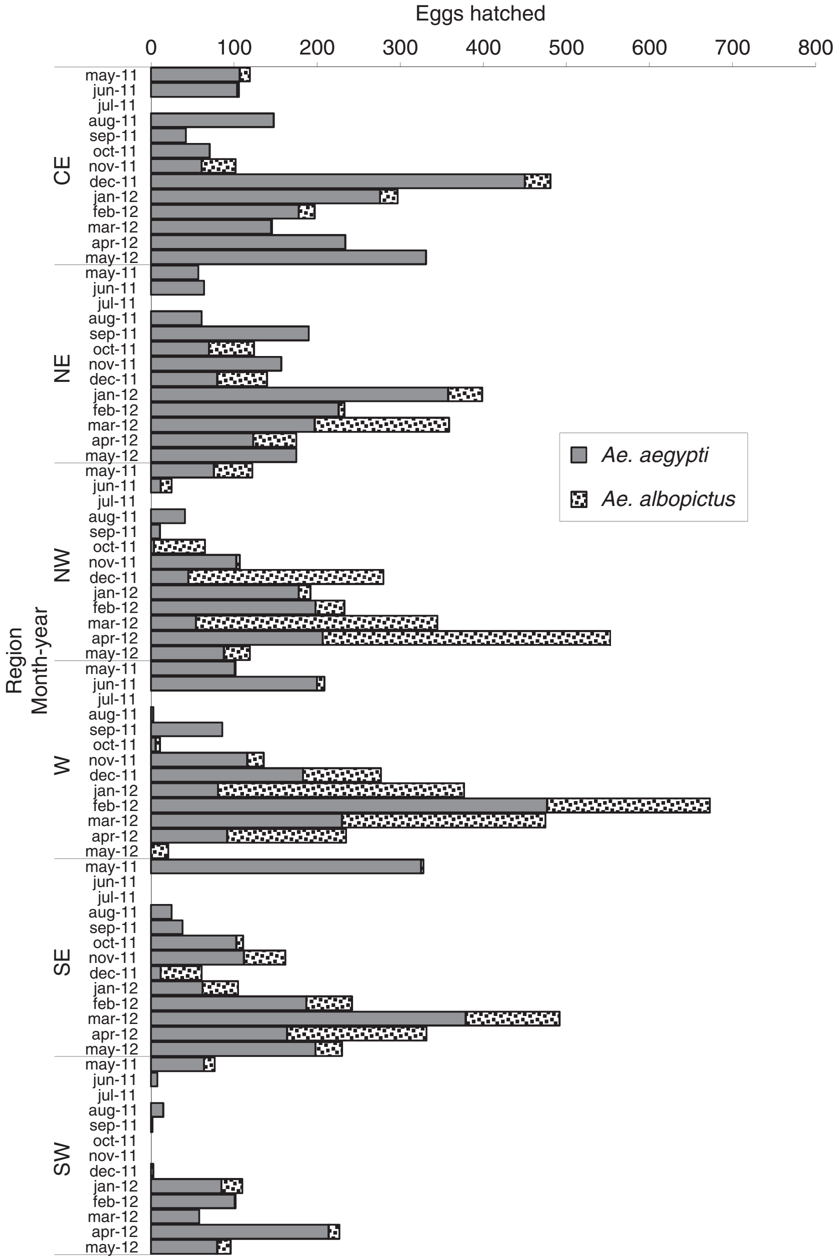

Figure 5 Species hatched from eggs collected, by region and month of collection.

(IBGE 2010; Khormi & Kumar 2011). Moreover, the observed seasonality of the presence of vectors is concurrent with the seasonality of cases, which occur principally during hot periods (Morin *et al.* 2013). In our study, entomological indicators and human cases were in complete agreement. Because the period of the greatest heat in Brazil extends beyond the summer months, the entomological indicators increased from August to April.

The association with rainfall described by Pessanha *et al.* (2011) suggests that rainfall provided physical and climatic conditions favourable to the development of eggs and to the increased survival of the mosquito. However, extreme rainfall conditions are not associated with vector presence over time, as the relationship between vector presence and rainfall is best described by a polynomial curve (Figure 3a). This pattern may result from the elimination of larvae from overflowing containers.

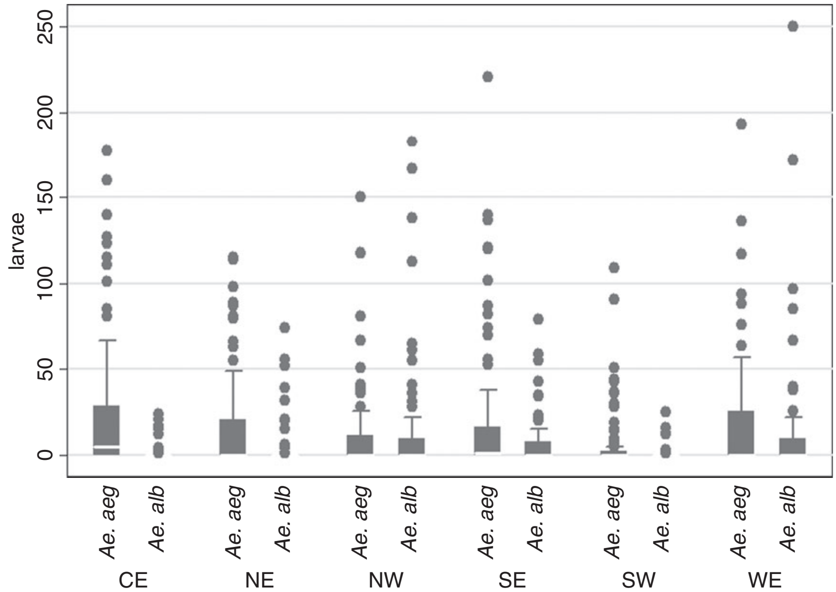

Figure 6 Boxplots of species by region. Number of larvae of each species (*Ae. aegypti/Ae. albopictus*) identified in Divinopolis during the 13 months of collection.

In our study, the presence of the vector was significantly influenced by temperature variation ($P < 0.05$) as expressed in terms of the mean of minimum temperature. This relationship has also been reported by Carvalho-Leandro *et al.* (2010). The highest values were recorded from December 2011 to April 2012, coinciding with the highest average temperatures occurring during the analysed period. A nonlinear relationship was observed, and the number of eggs increased exponentially with the minimum temperature. The higher temperatures provided better conditions for mosquito breeding (Farnesi *et al.* 2009; Chen & Hsieh 2012) and, consequently, a greater probability of transmitting DENV. Temperature influences the blood feeding of females and accelerates the development of mosquitoes, reducing the extrinsic incubation period of the virus and increasing the longevity of the mosquito (Pessanha *et al.* 2011). 11 976 larvae hatched from the more than 25 000 eggs collected, resulting in a hatching rate of 47%, close to the 55% rate found by Pessanha *et al.* (2011) in Belo Horizonte. The larvae were hatched under controlled conditions with an average temperature of 25 °C. This temperature was selected in view of the influence of temperature on hatching (Silva & Silva 1999).

We observed a predominance of *Ae. aegypti* in all months, especially in the colder and drier months of August and September 2011. *Ae. albopictus* was not observed during these months. This species was originally an inhabitant of wild areas but has become an urban species in recent years, adapting to environments previously inhabited only by *Ae. aegypti* and producing niche overlap between the two species (San Martin *et al.* 2010). Our data are consistent with the results of Honorio *et al.* (2009), who observed a higher abundance of *Ae. albopictus* (59%) than *Ae. aegypti* (41%) in forest areas of Rio de Janeiro. These data show the importance of further study of the behaviour and adaptation of *Ae. albopictus*, as this species is a potential disease vector (Gratz 2004; Alencar *et al.* 2008; Paupy *et al.* 2009). However, *Ae. albopictus* still preserves behaviour patterns used in its wild habitats, such as the use of peridomestic breeding and oviposition. These behaviours make it more vulnerable to rainfall and more likely to live in less urbanised places. This latter characteristic is reflected by the higher prevalence of *Ae. albopictus* in the traps located in the less deforested areas of Divinopolis: the north-west, south-east and west. The presence of *Ae. albopictus* in wooded areas in Brazil has also been noted by other authors, such as Prophiro *et al.* (2011) and Honorio *et al.* (2009).

Effective dengue control has seldom been achieved in recent decades (Schaffner *et al.* 2013). Therefore, it is necessary to develop new and innovative approaches for the effective control of the species. Lambrechts *et al.* (2010) concluded that *Ae. albopictus* most likely continues to spread globally regardless of efforts to prevent its expansion. Additionally, *Ae. albopictus* transmits other arboviruses and can be considered a secondary dengue vector (Thenmozhi *et al.* 2007; Alencar *et al.* 2008; Paupy *et al.* 2009; Lambrechts *et al.* 2010). In Espírito Santo State, Degallier *et al.* (2003) did not isolate DENV from male or female mosquitoes bred from immature stages. This result suggests that vertical transmission most likely did not occur during the final phase of this epidemic. However, the author advises that such results do not exclude the possibility that this mosquito may become an efficient vector of dengue and other arboviruses in the future. Other recent studies have also isolated DENV from *Aedes* spp. mosquitoes. For example, DENV was isolated by Figueiredo *et al.* (2010) from *Ae. albopictus* collected in the city of Santos (SP) and by Pessanha *et al.* (2011). More recently, Martins *et al.* (2012), in a study conducted in the city of Fortaleza (CE), isolated serotypes 2 and 3 from *Ae. albopictus* larvae and pupae collected in an urban area. Thus, this study highlights the need to control both vectors, not only *Ae. aegypti*. In general, however, control measures are currently only applied to *Ae. aegypti* (Thenmozhi *et al.* 2007; Alencar *et al.* 2008; Paupy *et al.* 2009; Erickson *et al.* 2010; Brady *et al.* 2014).

The average household income showed a low correlation with the presence of eggs of *Aedes* spp. The population density did not influence the presence and oviposition rate of mosquitoes, a result that differs from the findings of previous studies. Population density has been associated with mosquito density by other authors, that is the more inhabitants per square kilometre (hab/km^2), the more infested the region is likely to be Reiter and Gubler (1997). In locations with a highly concentrated human population, female mosquitoes have diverse artificial breeding locations and numerous food sources at their disposal (Nunes *et al.* 2011). The good correlation between the presence of vectors in ovitraps and accumulated dengue incidence by region (2007–2013) agrees with the findings of other studies and suggests that the presence of vectors in ovitraps may represent a good predictor of future dengue outbreaks (Chadee 2009).

Conclusions

Our results show direct correlations between temperature, precipitation and urbanised areas and the vector density. Moreover, the rates of occurrence of *Ae. albopictus* in Divinopolis are high, with seasonal and spatial variations in the distribution of *Ae. aegypti* and *Ae. albopictus*. In particular, the number and local prevalence of *Ae. albopictus* increased beyond the expected levels, consistent with the results of previous reports worldwide. These data suggest that *Ae. albopictus* are distributed differently in urban and forest habitats and that both species could be highly abundant in transitional areas that have both urban and peri-urban characteristics. In this study, *Ae. aegypti* were found to be predominant, corroborating previous reports of dengue epidemics in many parts of Brazil, elsewhere in the Americas and in other countries.

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References

Alencar CHM, Albuquerque LM, Aquino TMF *et al.* (2008) Potencialidades do *Aedes albopictus* como vetor de arboviroses no Brasil: um desafio para a atenção primária. *Revista de APS* **11**, 459–467.

Barreto ML & Teixeira MG (2008) Dengue no Brasil: situação epidemiológica e contribuições para uma agenda de pesquisa. *Estudos Avançados* **22**, 53–72.

Benedict MQ, Levine RS, Hawley WA & Lounibos LP (2007) Spread of the tiger: global risk of invasion by the mosquito *Aedes albopictus*. *Vector-Borne and Zoonotic Disease* **7**, 76–85.

Brady OJ, Golding N & Pigott DM (2014) Global temperature constraints on *Ae. aegypti* and *Ae. albopictus* persistence and competence for dengue virus transmission. *Parasites & Vectors* **7**, 338.

Braga IA & Valle D (2007) *Aedes aegypti*: histórico do controle no Brasil. *Epidemiologia e Serviços de Saúde* **16**, 113–118.

Braks MAH, Honorio NA, Lourenco-De-Oliveira R *et al.* (2003) Convergent habitat segregation of *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae) in southeastern Brazil and Florida. *Journal of Medical Entomology* **40**, 785–794.

Camara FP, Theophilo RLG, dos Santos GT *et al.* (2007) Regional and dynamics characteristics of dengue in Brazil: a retrospective study. *Revista da Sociedade Brasileira de Medicina Tropical* **40**, 192–196.

Carvalho-Leandro D, Ribeiro ALM, Rodrigues JSV *et al.* (2010) Temporal distribution of *Aedes aegypti* Linnaeus (Diptera, Culicidae), in a Hospital in Cuiaba, State of Mato Grosso, Brazil. *Revista Brasileira de Entomologia* **54**, 701–706.

Chadee DD (2009) Oviposition strategies adopted by gravid *Aedes aegypti* (L.) (Diptera: Culicidae) as detected by ovitraps in Trinidad, West Indies (2002–2006). *Acta Tropica* **111**, 279–283.

Chen SC & Hsieh MH (2012) Modeling the transmission dynamics of dengue fever: implications of temperature effects. *Science of the Total Environment* **431**, 385–391.

Coelho GE, Burattini MN, Teixeira MD *et al.* (2008) Dynamics of the 2006/2007 dengue outbreak in Brazil. *Memórias do Instituto Oswaldo Cruz* **103**, 535–539.

Consoli RAGB & Lourenço-de-Oliveira R (1994) *Principais Mosquitos de Importância Santitária no Brasil*. Editora Fiocruz, Rio de Janeiro, RJ.

Decker KD (2012) Dengue fever: re-emergence of an old virus. *The Journal for Nurse Practitioners* **8**, 389–393.

Degallier N, Teixeira JM, Soares SS *et al.* (2003) *Aedes albopictus* may not be vector of dengue virus in human epidemics in Brazil. *Revista de Saúde Pública* **37**, 386–387.

Dick OB, San Martin JL, Montoya RH *et al.* (2012) Review: the history of dengue outbreaks in the Americas. *American Journal of Tropical Medicine and Hygiene* **87**, 584–593.

Erickson RA, Presley SM, Allen LJS *et al.* (2010) A dengue model with a dynamic *Aedes albopictus* vector population. *Ecological Modelling* **221**, 2899–2908.

Farnesi LC, Martins AJ, Valle D & Rezende GL (2009) Embryonic development of *Aedes aegypti* (Diptera: Culicidae): influence of different constant temperatures. *Memórias do Instituto Oswaldo Cruz* **104**, 124–126.

Fay W & Perry AS (1965) Laboratory studies of ovipositional preferences of *Aedes aegypti*. *Mosquito News* **25**, 276–281.

Figueiredo ML, Gomes AC, Amarilla AA *et al.* (2010) Mosquitoes infected with dengue viruses in Brazil. *Virology Journal* **7**, 152.

Gomes AC (1998) Medidas dos níveis de infestação urbana para *Aedes* (Stegomyia) *aegypti* e *Aedes* (Stegomyia) *albopictus* em programas de Vigilância Entomológica. *Informe Epidemiológico do Sistema Único de Saúde* **7**, 49–57.

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

Honorio NA, Castro MG, Barros FSM *et al.* (2009) The spatial distribution of *Aedes aegypti* and *Aedes albopictus* in a transition zone, Rio de Janeiro, Brazil. *Cadernos de Saúde Pública* **25**, 1203–1214.

IBGE (2010) *Instituto Brasileiro de Geografia e Estatística - CENSO 2010*.

INMET (2012) *Instituto Nacional de Meteorologia*.

Khormi HM & Kumar L (2011) Modeling dengue fever risk based on socioeconomic parameters, nationality and age groups: GIS and remote sensing based case study. *Science of the Total Environment* **409**, 4713–4719.

Kobayashi M, Nihel N & Kurihara T (2002) Analysis of northern distribution of *Aedes albopictus* (Diptera: Culicidae) in Japan by geographical information system. *Journal of Medical Entomology* **39**, 4–11.

Lambrechts L, Scott TW & Gubler DJ (2010) Consequences of the expanding global distribution of *Aedes albopictus* for dengue virus transmission. *Plos Neglect Tropical Disease* **4**, 646.

Le Goff G, Boussès P, Julienne S *et al.* (2012) The mosquitoes (Diptera: Culidae) of Seychelles: taxonomy, ecology, vectorial importance, and identification keys. *Parasites & Vectors* **5**, 207.

Martins VEP, Alencar CH, Kamimura MT *et al.* (2012) Occurrence of natural vertical transmission of dengue-2 and dengue-3 viruses in *Aedes aegypti* and *Aedes albopictus* in Fortaleza, Ceará, Brazil. *PLoS ONE* **7**, 1–9.

Ministério da Saúde: FUNASA – Fundação Nacional de Saúde (2001) *Dengue – Instruções Para Pessoal de Combate ao Vetor: Manual de Normas Técnicas*, 3° edição, ver. Ministério da Saúde, Brasília, 84.

Morin CW, Comrie AC & Ernst K (2013) Climate and dengue transmission: evidence and implications. *Environmental Health Perspectives* **121**, 11–12.

Nogueira RMR, Zagner SMO, Martins ISM *et al.* (1991) Dengue hemorrhagic fever/dengue shock syndrome (DHF/DSS) caused by serotype 2 in Brazil. *Memórias do Instituto Oswaldo Cruz* **86**, 269.

Nogueira RMR, Miagostovich MP, Filipis AMP *et al.* (2001) Dengue virus type 2 in Rio de Janeiro, Brazil. *Memórias do Instituto Oswaldo Cruz* **96**, 925–926.

Nunes LS, Trindade RBR & Souto RNP (2011) Avaliação da atratividade de ovitrampas a *Aedes* (Stegomyia) *aegypti* Linneus (Diptera: Culicidae) no bairro Hospitalidade, Santana, Amapá. *Biota Amazônia* **1**, 26–31.

Padmanabha H, Correa F, Legros M *et al.* (2012) An eco-physiological model of the impact of temperature on *Aedes aegypti* life history traits. *Journal of Insect Physiology* **58**, 1597–1608.

PAHO (1947) Pan American Health Organization. I Direct Council of the Pan American Health Organization. Resolution CD1.R1. Continental *Aedes aegypti* eradication. Available at: http://www.paho.org/English/GOV/CD/ftcd_1.htm#R1. [Accessed in August 28, 2014].

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

Pedro A (1923) O dengue em Nictheroy. *Brazil-Médico* **13**, 173–177.

Pessanha JEM, Caiaffa WT, Cecilio AB *et al.* (2011) Cocirculation of two dengue virus serotypes in individual and pooled samples of *Aedes aegypti* and *Aedes albopictus* larvae. *Revista da Sociedade Brasileira de Medicina Tropical* **44**, 103–105.

Ponce G, Flores AE, Badii MH *et al.* (2004) Bionomía de *Aedes albopictus* (Skuse). *Revista Salud Pública y Nutrición* **5**, 1–11.

Prophiro JS, Silva OS, Luna JED *et al.* (2011) *Aedes aegypti* and *Aedes albopictus* (Diptera: Culicidae): coexistence and susceptibility to temephos, in municipalities with occurrence of dengue and differentiated characteristics of urbanization. *Revista da Socidade Brasileira de Medicina Tropical* **44**, 300–305.

Reiter P & Gubler DJ (1997). Surveillance and control of urban dengue vectors. In: *Dengue and Dengue Hemorrhagic Fever*. (eds DJ Gubler & G Kuno) CAB International, New York, NY, pp. 425–462.

Reiter P, Amador MA & Colon N (1991) Enhancement of the CDC ovitrap with hay infusions for daily monitoring of *Aedes aegypti* populations. *Journal of the American Mosquito Control Association* **7**, 52–55.

Rezza G (2012) *Aedes albopictus* and the reemergence of Dengue. *BMC Public Health* **12**, 72.

San Martin JL, Brathwaite O, Zambrano B *et al.* (2010) The epidemiology of dengue in the americas over the last three decades: a worrisome reality. *The American Journal of Tropical Medicine and Hygiene* **82**, 128–135.

Schaffner F, Medlock JM & Bortel WV (2013) Public health significance of invasive mosquitoes in Europe. *Clinical and Microbiology Infection* **19**, 685–692.

Schatzmayr HG, Nogueira RMR & Rosa APAT (1986) An outbreak of dengue vírus at Rio de Janeiro. *Memórias do Instituto Oswaldo Cruz* **81**, 245–246.

SEMUSA (2001) *Secretaria Municipal de Saúde de Divinópolis/ MG. Boletim Epidemiológico*.

SEMUSA (2010) *Secretaria Municipal de Saúde de Divinópolis/ MG. Boletim Epidemiológico*.

Silva HHG & Silva IG (1999) Influência do período de quiescência dos ovos sobre o ciclo de vida de *Aedes aegypti* (Linnaeus, 1762) (Diptera, Culicidae) em condições de laboratório. *Revista da Sociedade Brasileira de Medicina Tropical* **32**, 349–355.

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

SINAN (2014) System for the Reporting of Notifiable Conditions. Available at: http://dtr2004.saude.gov.br/sinanweb/tabnet/dh?sinannet/dengue/bases/denguebrnet.def. [Accessed in March 13, 2014].

Thenmozhi V, Hiriyan JG & Tewari SC (2007) Natural vertical transmission of Dengue Virus in *Aedes albopictus* (Diptera: Culicidae) in Kerala, a Southern Indian State. *Japanese Journal of Infectious Diseases* **60**, 245–249.

Tolle MA (2009) Mosquito-borne diseases. *Current Problems in Pediatric and Adolescent Health Care* **39**, 97–140.

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